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Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert

A CTB Verification Exercise Using Commercial Satellite Imagery

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This paper describes how commercial satellite imagery was used along with news reports and published scientific articles to investigate the December 1995 allegations of Indian nuclear test preparations in the Rajasthan Desert. Taking the allegations against India as an example of a future CTB compliance dispute, the investigation was conducted to test the utility of commercial satellite imagery for CTB verification. The technical inquiry produced a series of findings on India's nuclear testing history and on the recent nuclear test allegations. These findings included the exact location of the subsidence crater created by the May 18, 1974 nuclear test, the discovery of an adjacent military range near Khetolai village, and the observation of recent large-scale, unusual activity at this military range in the immediate vicinity of the 1974 test site. The image-derived information was used to sift fact from fiction in the conflicting media reports. It was then integrated into the collection of credible evidence and analyzed to determine whether the observed activity at the Khetolai military range was conventional, missile testing, nuclear, or innocuous.

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Our analysis led to three main conclusions. First, the Khetolai military range has a history of nuclear test activity. It was used for the May 18, 1974 nuclear test, and there is credible evidence from four different sources that indicates shafts were constructed in the early 1980s for two additional nuclear tests there. Second, there is believable evidence that supports the claim of planned Prithvi field testing at the Khetolai military range. An Indian news report with four verified factual claims described the planned missile activity, and 1:500,000 scale US DMA maps show five nearby military operation areas that could be well-suited as missile impact points. Third, a significant fraction of the image-derived evidence was consistent with nuclear test preparations, planned Prithvi missile testing, or a combination of both. Thus, nuclear test preparations and planned Prithvi field testing are each plausible, non-exclusive explanations for the observed new activity at the Khetolai military range.

The paper ends with an assessment of the implications of the case study to the broader issue of CTB verification and compliance. The conclusions include a discussion on the lessons that were learned from the verification exercise, and commentary on the value of existing commercial satellite imagery for addressing future CTB compliance issues.

INTRODUCTION

On December 15, 1995, the *New York Times* reported that India was preparing to conduct a nuclear test in the Rajasthan Desert.[1] The following day, the *Washington Post* ran an article that also reported Indian preparations for a nuclear explosive test in northwest India.[2] These two articles generated a cacophony of expert and official responses, ranging from strongly worded declarations that the allegations of test preparations were definitely false to opposing statements that the reports were definitely true. Table 1 shows the spectrum of the responses.

The recent allegations of Indian nuclear test preparations represent a type of compliance issue that the international community could face in the future under a comprehensive test ban (CTB) regime. A state could suddenly be accused of preparing to violate or break out of the CTB treaty with little or no evidence presented to support the allegation. Immediately after such a development occurred, experts and officials from accusing and accused states could end up exchanging conflicting statements on the veracity of the allegations—as exemplified by table 1. The "post-test" verification technologies for the CTB—hydroacoustic, infrasound, radionuclide, and seismic—would do little to resolve the matter in advance of an actual test. And an on-site inspection may not be invoked due to the lack of geographic and historical information on the suspected site or due to the absence of a CTB provision that would allow a "pre-test" inspection.

Whether allegations of nuclear test preparations are true or not, state-parties to a CTB regime would most likely have a keen interest in determining the facts as quickly and as accurately as possible. It may be desirable to derive these facts from open source data so that the information could be collected by multiple states independently and distributed to allies and adversaries freely. Such decentralized information would be more difficult to alter and consequently could be more credible in an untrustworthy regional or international environment.

One open source of decentralized information that could be used to investigate reports of nuclear test preparations is commercial satellite imagery. Such imagery has already been used by several researchers to detect preparations and analyze surface scarring at known nuclear test sites.[3] The utility of commercial satellite imagery for verifying a comprehensive nuclear test ban has also been critically evaluated.[4] The results of these studies to date have demonstrated the value of existing commercial imaging satellites for monitoring ongoing nuclear testing programs at declared nuclear test sites. However, these studies have not established the utility of such imagery for detecting clandestine testing activity anywhere inside a country's borders.

This investigation of the reported Indian nuclear test preparations was done to test the utility of commercial satellite imagery for resolving CTB compliance issues that could arise *before* a nuclear test has taken place. Taking the allegations against India as an example of a future CTB compliance dispute, commercial satellite images from a variety of sensors were used along with news reports to determine what activity (if any) was happening in the Rajasthan Desert. This case study attempted to answer a few key technical questions: Can the best available commercial satellite imagery confirm reports of nuclear test preparations and dispel those that are inaccurate? If so, can this information be published in a timely manner to expose a state's nuclear testing intentions before such a state invokes its treaty withdrawal option or before it attempts to conduct a nuclear explosive test covertly? Conversely, can this information be used to vindicate a state that has been falsely accused due to malintent or misinterpretation of the available evidence?

The next section of this paper contains a comprehensive literature review of historical and recent media reports on Indian nuclear testing activities from 1974 to the present. This information was essential for determining the specific geographic portion of India that required overhead observation. The articles provided a wealth of unique information. Some of the details within these reports were consistent; others were contradictory. The section ends with an analysis of the media reports as a hypothetical CTB compliance controversy.

Table 1: Expert and official opinions on the veracity of reports on Indian nuclear test preparations in the Rajasthan Desert.

Opinion	Responses	Reference
Definitely False	"There is no truth in this," said Arif Khan, chief spokesman for the (Indian) External Affairs Ministry. He said the intelligence agencies apparently spotted military activities that were not related to India's nuclear program. "There are routine military exercises in this area because it is close to the border with Pakistan," Khan said.	Tim Weiner, "India Suspected of Preparing for A-Bomb Test," *New York Times*, December 15, 1995, p. A6.
	Shive Mukherjee, Press Minister of the Indian Embassy here (US), said today that activities at the nuclear test site were army exercises whose "movements have been absurdly misinterpreted."	Tim Weiner, "US Suspects India Prepares to Conduct Nuclear Test," *New York Times*, Late Edition, December 15, 1995, p. A9.
	"Nonsense," said the father of the first Indian atomic bomb Raja Ramanna. Describing the report as "a big lie," he said. The man who is credited with the successful conduct of the Pokharan test, R. Dastidar, said: "Personally, I would not believe the NYT report. US sources are not trustworthy."	Srinivas Laxman, "NYT Report of N-test a Big Lie: Ramanna," *The Times of India*, December 17, 1995, p. 9.
	"The answer is no," (Indian External Affairs Minister Pranab) Mukherjee said at a news conference in response to a question on whether India intends to stage a nuclear test. "Those reports are speculative and baseless," Mukherjee said.	Lisa Vaughan, "India Says Not Planning Nuclear Weapon Test," Reuters, December 19, 1995.
	"(W)e showed our capability to be able to do an explosion experiment at Pokharan," said P.K. Iyengar, the former Chairman of the Indian Atomic Energy Commission. "Since then, we haven't done any testing of a device nor is there a program to test a device." During the question and answer session, he added, "I think we have false rumors that goes around saying that they (the Indian government) are trying to test another weapon. That's not true."	P.K. Iyengar, "India's Nuclear Program: Past and Future," presented at the Henry L. Stimson Center, Washington DC, May 23, 1996.
Probably False	"I can't see India conducting a nuclear test," P.R. Chari, a defense analyst at India's Center for Policy Research, said. "The costs would be so enormous and the benefits would be so trivial that they would not do it." Chari called the American assertions highly "speculative." "This is putting two and two together and making 22," he said	Hema Shukla, "Indian Expert: Nuclear Test Unlikely," UPI, December 16, 1995.
Partially False	India is preparing to test the Prithvi missile with a conventional warhead to its maximum range of 150 km at Pokharan. It was this activity that the US spy satellite picked up and which intelligence officials suspected as India's preparation for another nuclear test.	Pravin Sawhney, "Preparations at Pokharan Site Reportedly for Missile Test," *The Asian Age*, December 19, 1995, pp. 1, 4.

Table 1: (Continued) Expert and official opinions on the veracity of reports on Indian nuclear test preparations in the Rajasthan Desert.

Opinion	Responses	Reference
No Comment	Chairman of the (Indian) Atomic Energy Commission (AEC) R. Chidambaram said: "I do not have to respond to every irresponsible report in the American media." Former AEC Chairman Homi Sethna chose not to comment.	Srinivas Laxman, "NYT Report of N-test a Big Lie: Ramanna," *The Times of India*, December 17, 1995, p. 9.
Ambiguous	"It is a totally speculative kind of report," (Arif Khan, chief spokesman for India's External Affairs Ministry) said. When a reporter asked if the speculation was true or false, he replied: "There is no such thing as true speculation. Speculation is speculation."	John Burns, "India Denies Atom-Test Plan But Then Turns Ambiguous," *New York Times*, December 16, 1995, p. 4.
	Director of the (Indian) Bhabha Atomic Research Center (BARC) A.N. Prasad called it a "speculative report." "Satellites keep recording various types of activities," he added.	Srinivas Laxman, "NYT Report of N-test a Big Lie: Ramanna," *The Times of India*, December 17, 1995, p. 9.
Possibly True	All this could have more than one explanation, but the possibility that it could be preparations for a nuclear test cannot be ruled out.	Prem Shankar Jha, "Maintaining India's Nuclear Option," *The Hindu*, December 30, 1995, p. 12.
Probably True	"I believe there are some preparations. We do not know if it will be a Smiling Buddha 2," said (Pakistan) President Farooq Ahmad Khan Leghari in a reference to the 1974 test which was code-named Smiling Buddha.	"Pakistan Assures Appropriate Response to a New Nuclear Test by India," *Deutsche Presse-Agenteur*, December 18, 1995.
Definitely True	"The relationship between India and Pakistan continues to be unsatisfactory and the potential for conflict is high," said John Deutch, Director of Central Intelligence. "India is making preparation for a nuclear test, and we assume that if one nation conducts a test, the other will follow."	John Deutch, "Worldwide Threat Assessment," Prepared statement before the US Senate Intelligence Committee, Washington DC, February 22, 1996.
	On March 8, (Indian External Affairs Minister) Pranab Mukherjee made a sensational disclosure to a select group of analysts and academics in New Delhi on India's nuclear capability and reported preparations for a nuclear test. He said: "We were to exercise the (test) option last year (1995)." But "something happened..." However, "we may exercise it later."	Praful Bidwai, "Battle for a Bona Fide CTBT," *The Economic Times Mumbai*, April 1, 1996, p. 7.

The following sections explain how commercial satellite imagery was obtained, processed, and analyzed to locate the geographic area where the Indian nuclear testing activities were said to have taken place. It provides the interpretation of the images and describes the discoveries that were made. This new information was used to assess the credibility of each media report and identify the activity that was found in the satellite imagery. The paper concludes with a summary of the body of evidence obtained from this investigation and commentary on the value of existing commercial satellite imagery for addressing CTB compliance issues that could arise before the occurrence of a nuclear test.

PUBLISHED REPORTS ON INDIAN NUCLEAR TESTING ACTIVITY

The May 18, 1974 Nuclear Test

The available literature on Indian nuclear testing activity goes back to 1974 when India conducted its first nuclear explosive test on May 18 of that year. The test was conducted underground in the Rajasthan Desert. According to a Bhabha Atomic Research Center (BARC) report, the plutonium device was placed at the bottom of a 107 meter shaft and detonated at 08:05 hrs IST generating a nuclear yield of approximately 12 kilotons TNT.[5] Shortly after the explosion, a subsidence crater formed. The average radius of the apparent crater was 47 meters and the crater depth with respect to the "pre-shot" ground surface was 10 meters.[6]

Plate 1 shows a picture of the crater and cable poles leading to the ground zero. The picture was taken from a helicopter approximately one hour after the detonation of the nuclear device.[7] Several publications printed pictures of the crater, including BARC, the *Illustrated Weekly of India*, *India Abroad*, and *India Today*.[8] However, the scale of the photo and the exact geographic location of the crater were not provided.[9]

Media reports on the May 18, 1974 test provide contradictory clues on the geographic location of the subsidence crater. A *Science Today* article described how scientists and officials watched the explosion from "a tower 4.5 km away at Pokhran."[10] A *Patriot* article stated the detonation point was further away—"about 20 km from Pokharan town."[11] A *Times of India* article asserted that the closest inhabited area to the detonation point was not Pokharan, but rather the village of Loharki.[12] An *Indian Express* article was consistent with this report, claiming that the distance from Loharki to the 1974 detonation point was three kilometers.[13] A *Business Standard* article claimed a slightly longer distance of around four kilometers.[14] An article in *Sunday Magazine*

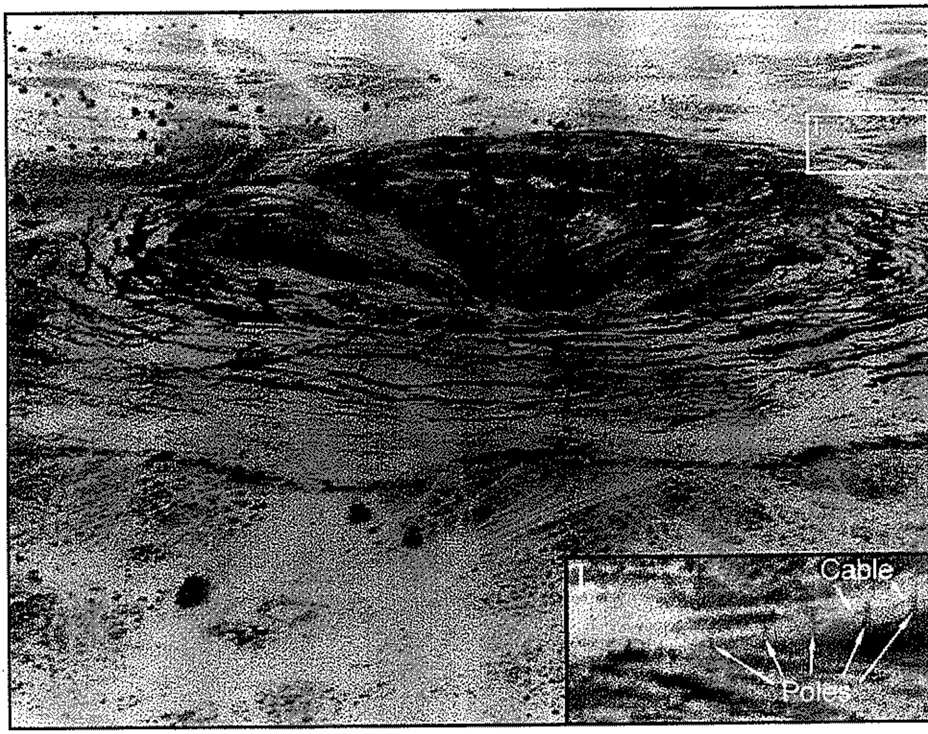

Plate 1: Photo of the crater taken from a helicopter on May 18, 1974 approximately one hour after the nuclear explosion. The inset is an enlargement of section I. showing the cable and poles leading to the center of the crater. (Source: Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 432).

provided more details stating that the 1974 test was conducted in a dry well near the abandoned village of Malka.[15] Figure 1 shows the various areas where the May 18, 1974 test reportedly occurred.

Figure 1 also contains the seismic estimate of the test location as reported by the International Seismological Center (ISC). The ISC reported that the test registered 4.9 on the Richter scale and took place at 26.99 $\pm$ .028° N, 71.80 $\pm$ .033° E in the general vicinity of Pokharan.[16] This location estimate could have systematic errors of around 15 km and random errors up to 10 km.[17] As a result, the seismic location estimate alone proved inadequate for filtering the conflicting media reports on the location of the May 18, 1974 test (see solid circle in figure 1).

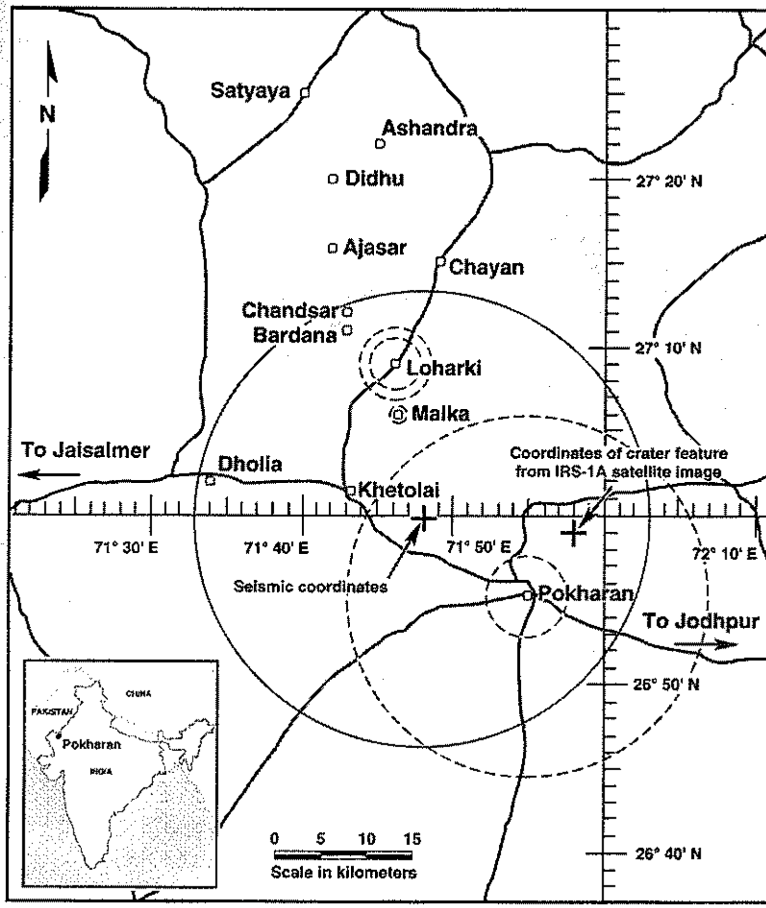

Figure 1: The different places where the May 18, 1974 Indian nuclear test may have occurred. The area inside each dotted circle represents the relative test location provided by different news reports. The area inside the solid circle represents the seismic location estimate—the region where the nuclear test most likely took place. The radius of the solid circle is the sum of the estimated systematic error (15 km) and random error (10 km).

The road network shown on the map was obtained from the November 1987 1:1,000,000 scale Operational Navigation Chart (ONC) H-8 produced by the US Defense Mapping Agency Aerospace Center. The villages and towns were located on two 1955 1:250,000 scale map sheets (NG-42-04 and NG-42-08) produced by the US Army Map Service.[18]

In 1992, one researcher claimed to have located the crater formed by the Indian nuclear test on a commercial satellite image of the Pokharan area.[19] The October 26, 1988 image was acquired by the Indian remote sensing satellite, IRS-1A. The satellite acquired the image at a 36.25 meter ground sample

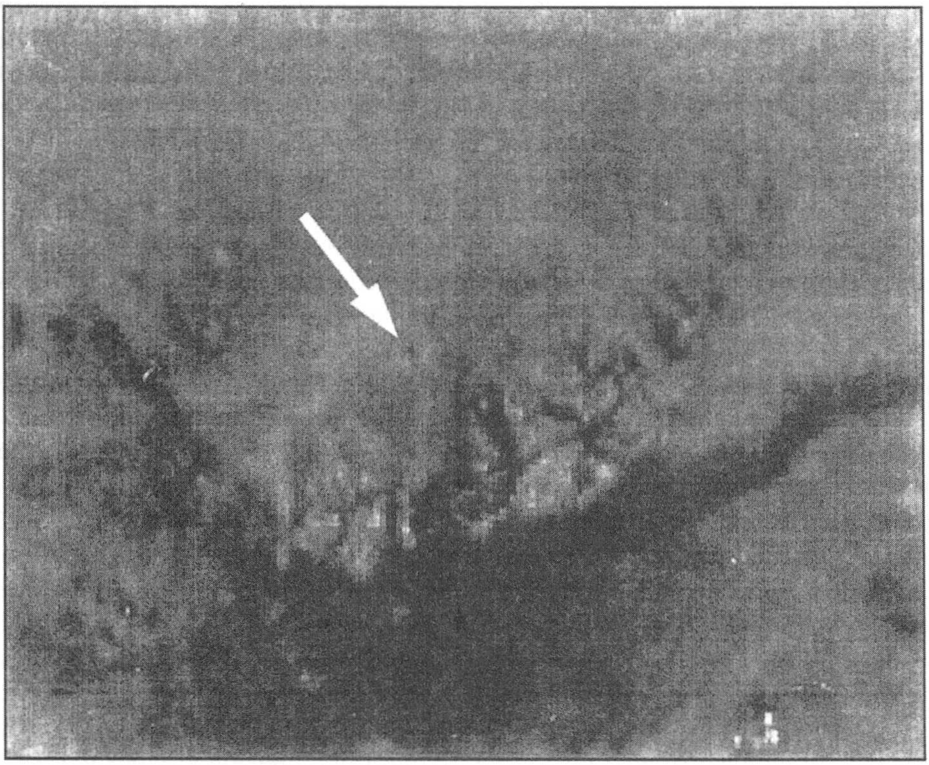

Plate 2: Black and white reproduction of the October 26, 1988 IRS-1A subscene showing a nine pixel feature that was identified as the May 18, 1974 subsidence crater. The reproduction preserved the spatial and textural detail from the original subscene. (Source: Jasani, "Civil Observation Satellites and Arms Control Verification," p. 96).

distance.[20] A nine pixel feature was identified as the subsidence crater and located at 26.982° N, 71.965° E—approximately seven km northeast of Pokharan (see figure 1 and plate 2).

However, the spatial resolution of the IRS-1A image was too coarse to match the feature with the crater shown in the helicopter photo (see plate 1); it was not readily apparent that the identified nine pixel feature was indeed the May 18, 1974 crater (see plate 2). Consequently, the exact location of the crater was still not known with certainty. While there were multiple claims on the geographic location of the test, only one—at most—could be correct.

Alleged Indian Nuclear Test Activity in 1981

On April 27, 1981, US Senator Alan Cranston publicly accused India of preparing to conduct a nuclear explosives test. Citing US officials in the executive branch, he stated that India began nuclear test preparations in February 1981 at a site in the Thar Desert at Pokharan about 100 miles southeast of the Pakistani border, "alongside the site of India's 1974 bomb test."[21] He described the activity as "surface excavations for burial of a nuclear warhead—for an underground test."[22]

About a week later, the *Indian Express* ran an article that described their correspondent's recent visit to the Pokharan area. The article reported that nine villages near Pokharan "may soon be evacuated to make room for another nuclear explosion." The article included the names of the nine villages: Ashandra, Ajasar, Bardana, Chandsar, Chayan, Dholia, Didhu, Loharki, and Satyaya (see figure 1).[23] The correspondent cited Mr. Gokul Das, the deputy leader of Loharki, as one of the sources that believed a second Indian nuclear test was imminent. The Loharki village official was quoted as saying that, "Barbed wire fencing suddenly went up three months ago [January or February 1981] around three kilometers south of the old blast site..." The area enclosed by the fencing was "roughly eight kilometers long and three kilometers wide." He added that the area was part of a firing range for tanks and artillery. Gulab Singh, the village leader of Loharki, stated that the district authority issued orders in December 1980 and February 1981 that prohibited the local villagers from entering the newly secured area for a one year period.

About one or two months after the fences were constructed, Mr. Gokul Das received "official word" on a meeting with eight neighboring villages to discuss the evacuation of all nine villages for a four-day period. Rattan Singh, the head of Ajasar village, also heard that the villages were to be evacuated for four days. In the end, the meeting reportedly never took place.

The *Indian Express* article concluded with information from Mr. P. R. S. Menon, the sub-divisional officer at Pokharan, that raised doubt on any Indian plans for a nuclear test. He claimed that he had "no official information regarding the takeover of any villages in his division." He also noted that vehicles with Atomic Energy Commission markings freely roamed the area before the May 1974 test, but "no such vehicle was in evidence now." There were no follow-up reports on the plans for evacuating all nine villages, and there is no evidence of an Indian nuclear test in 1981.

Alleged Indian Nuclear Test Activity in 1982

In early May 1982, an article in a weekly Calcutta publication, *Sunday Magazine*, reported that "[f]or the past one year, army units posted in the vicinity of Pokhran have been engaged in activities similar to the ones carried out before the 1974 blast." According to the villagers at Loharki, the Indian army "had cordoned off an area between the earlier test site of Malka and Khetolai (a village on the Pokhran-Jaisalmer road) and it seemed as if another blast was going to take place."[24] The villagers at Khetolai confirmed this account and added that, "... at night lights could be seen from the site. There was also the droning sound of [a] machine, perhaps a drill, heard in the night."

Loharki villagers claimed that military authorities held discussions with Gulab Singh, their village leader, on the possibility of evacuating for a few days. However, Mr. Singh contradicted this claim: "the army periodically visits the village, but no indication has been given by the army about any possibility of the village being evacuated for a nuclear blast."

These eyewitness accounts were never confirmed by subsequent press reports. There is also no evidence that a second Indian nuclear test was ever conducted. However, an article in *Jane's Intelligence Review* (JIR) recently claimed that Indian nuclear test preparations were underway during this time period. In 1995, senior Indian nuclear scientists told the JIR author in taped interviews that "open-source reports about India's preparations for nuclear tests in the early 1980s were accurate."[25] According to the scientists, a decision was made between 1978 and 1980 "to prepare the ground for two additional tests..." In the early 1980s, the Indian army participated in the drilling of the two holes, "which were completed under difficult circumstances..."

Alleged Indian Nuclear Test Activity in Late 1995

On December 15, 1995, the *New York Times* reported that US spy satellites had "recorded scientific and technical activity at the Pokharan test site in the Rajasthan Desert."[26] The article did not describe exactly what the alleged activity was and it expressed uncertainty on its purpose. The day after the NYT article was published, the *Washington Post* ran a similar article that described recent Indian efforts "to clean out a deep underground shaft for lowering a nuclear weapon into the earth."[27] It also detailed "possible preparations for instrumentation" that could be used to collect data from a nuclear explosion. The article claimed that the activity took place at a Pokharan site that has been maintained by India "for the past two decades."

Shortly after the US media reported recent Indian nuclear testing activity in the Rajasthan Desert, the Indian media collected and published information on the subject that they had obtained from their own independent sources. A December 18, 1995 *Times of India* article reported that the nuclear testing allegations were wrong, citing information from "senior defense officials." These officials told the *Times of India* that Pokharan consisted of four ranges labeled from 'A' through 'D.'[28] The officials stated that only range A was set aside for nuclear experiments and "here there has been no activity." They acknowledged that activity was taking place in the general area, but only in ranges B and C "which are used by the army." They added that ranges B-D "have been the site of exercises for many years, and there is nothing unusual in this." A December 19, 1995 *Jansatta* article supported the *Times of India* report. It also noted that Pokharan was "the arena where Indian forces go to conduct practice exercises."[29] The article claimed the existence of a site "reserved for the nuclear explosions," but asserted that it "is devoid of any activity."

On the same day the *Jansatta* article was published, the *Asian Age* ran a different story on Indian activities near Pokharan.[30] Like the *Times of India* article, it noted that the Pokharan area was divided into four ranges: "range A for artillery firing which needs a maximum open area of 40 km, range B is traditionally for armour exercises, range C is for the Indian air force and range D, where the 1974 peaceful nuclear implosion was conducted, is cordoned off as restricted area." The *Asian Age* article described range D as normally dormant. However, activity in range D "picked up" because India planned to "test the Prithvi missile with a conventional warhead to its maximum range of 150 km..."

Senior Indian artillery officers informed *Asian Age* in June 1994 that the Indian government had approved the "firing of a salvo of four Prithvi at Pokharan" because "an acquired massive range is available for the purpose." In May 1994, this plan was set aside "in view of the proximity of the Pokharan ranges to the border with Pakistan." Instead, the Prithvi was tested by the missile crews on June 4, 1994 and June 6, 1994 at the Orissa test range in eastern India.[31] In July 1995, senior artillery officers told the *Asian Age* that they were dissatisfied with these Prithvi user tests under "such controlled conditions," implying that more field tests were required "under real battlefield conditions."

According to the *Asian Age*, the observed activity in the vicinity of the 1974 nuclear explosion site related to testing "the mobility and preparation of the missile under field conditions." The need for field training was emphasized in the article "as Prithvi uses a liquid propellant which is highly toxic and corrosive."[32] There have been no further news reports on the outcome of these alleged field tests.

Subsequent Indian articles provided villagers' accounts on activities in the Pokharan area. A December 30, 1995 *Hindu* article described a recent visit by an Indian correspondent to villages around Pokharan.[33] According to the villagers, a new barbed wire fence was erected around the "vast site of the 1974 test." The article noted that "there is also evidence that earth moving equipment has been used." The villagers "claim that an entire new hill has been created from the excavated sand and mud." In addition, the correspondent described the possible presence of "a water pipe laid out to one of the villages." A January 3, 1996 *Hindustan Times* article made similar claims and described the presence of cabling: "These activities comprised fencing off the old test site, piling up earth to construct a huge sand dune, laying down cables, and so on."[34]

A January 1, 1996 article in the *Business Standard* provided more detailed information from the locals.[35] Like the *Hindu* and *Hindustan Times* articles, it reported that a "new, sturdy" fence was recently constructed around the 1974 explosion site. Pancha Ram, a Loharki farmer, was surprised the new fence was built because villagers were "using the area in and around the site for grazing their cattle." The farmer recalled that "soon after the first [1974] explosion grass and shrubs in the area were burnt, but, with good rains the greenery sprouted again." According to Bhairon Singh, a village worker, the cattle would even venture around the crater formed by the 1974 nuclear explosion.[36] But when the *Business Standard* correspondent tried to visit this area, "a guard came running to announce that the area was out of bounds." The guard added that "his superiors had issued instructions not to allow any civilians in the area."

Loharki villagers and Pokharan residents also noticed a significant increase in the number of army troops in the district. A school teacher in Pokharan observed a 17 kilometer long convoy on the highway from Jodhpur to Pokharan (see figure 1) that "was packed with defence hardware and heavy equipment, besides trucks carrying troops." The locals noted that annual military exercises occur in the area at this time of year, but "this is the biggest ever witnessed by them." They added that "no one seems to be aware of the reason for what looks like a change in the routine."

The *Business Standard* correspondent noted that Loharki villagers were not convinced that the recent activity related to preparations for a nuclear test. In contrast with the *Hindu* and *Hindustan Times* reports, the *Business Standard* article stated that the villagers have not "seen any large-scale earthmoving or civil construction activity." Man Singh, the head of Loharki village, stated: "We are not aware of any plans for another explosion." Army officials in Jodhpur speculated that the testing areas associated with the winter military maneuvers may have been mistaken for nuclear test preparations because conventional test ranges "come alive during this exercise."

Analysis of Media Reports as a Hypothetical CTB Compliance Issue

If the recent allegations against India happened under a CTB regime where India was a signatory to the treaty, many national governments, some nongovernmental organizations, and a few regional and international institutions would have a vested interest in answering one main question: were the charges of Indian nuclear test preparations true or false? To answer this question, analysts worldwide would investigate the matter. At the early stages of the inquiries, the available evidence would primarily be India's official responses to the allegations, India's nuclear testing history, and the media reports described in the previous sections.

Based on the available evidence, there would be cause for suspicion as well as reason for skepticism. India has already demonstrated the capability to develop and test a nuclear explosive device. Consequently, the media reports of Indian nuclear test preparations in 1981, 1982, and 1995 would have to be taken as a technical possibility. The establishment of a secured area in 1981 and the reports from village leaders of evacuation plans could have related to preparations for follow-on nuclear tests. The surface excavations and the nighttime operation of a machine that sounded like a drill, as reported in 1981 and 1982 respectively, could have been evidence of the shaft construction that was reportedly authorized to prepare the ground for two future nuclear tests. The local villagers' description of new security perimeters erected in 1995 and new restrictions on civilian access around the 1974 test site could have been precursors to increasingly clandestine activity. Their observation of a new hill of excavated sand and mud could have been evidence of drilling debris, borehole stemming material, or both.[37] Alternatively, the new hill could have been the by-product of the shaft cleaning that was reported in the *Washington Post*. And the laying out of cables could have been associated with the preparation of diagnostic equipment for nuclear test experiments. The affirmative remarks, ambiguous responses, and lack of comment from some Indian officials to the allegations could have been further indications of recent Indian nuclear test preparations (see table 1).

This information alone would have made India a potential suspect of imminent CTB violation or breakout. However, it would not have been adequate for answering several questions that raise doubts about the allegations. If the reports of evacuation planning and drilling in the early 1980s were true, why didn't an Indian nuclear test occur shortly thereafter? If the villagers' recent claims of new security perimeters and access restrictions around the 1974 test site were accurate, why did the *Times of India* and *Jansatta* articles claim that there was no activity at the site reserved for nuclear experiments? Perhaps the new security provisions were incorporated *after* the initial nuclear testing allegations were made in order to prevent the paparazzi from probing around conventional military areas? If the local villagers' recent observation of a new hill of excavated sand and mud were correct, why did the *Business Standard* report that local villagers have *not* witnessed "any large-scale earthmoving or civil construction?" Were some villagers merely crying wolf?

If the *New York Times* and *Washington Post* articles were accurate, why didn't the articles provide more specific information other than supposed shaft cleaning to prove that the observed activity was nuclear test preparations? If the *Asian Age* report of preparations for Prithvi missile testing near the 1974 test site was true, could that activity been incorrectly associated with nuclear test preparations? If winter military maneuvers were underway in the area, could the conventional military activity at the test ranges been mistakenly construed as nuclear test preparations? If so, the official Indian denials could have accurately stated that only conventional military exercises were happening in the area (see table 1).

ACQUISITION, PROCESSING, AND ANALYSIS OF COMMERCIAL SATELLITE IMAGERY

If the allegations against India were a CTB compliance dispute, analysts would seek to resolve the issue by completing three principal objectives:

(i) Collect new information from reliable, independent sources.
(ii) Separate fact from fiction in India's official responses, India's nuclear testing history, and the media reports.
(iii) Determine whether the body of evidence implicated or exonerated India.

This verification exercise tested the utility of commercial satellite imagery for completing these three objectives. Imaged portions of the Rajasthan Desert were obtained from the archives and recently acquired by commercial imaging satellites. Table 2 lists all of the satellite images that were used and explains why each specific image was selected for detailed analysis. The images were processed, enhanced, and interpreted in an attempt to fulfill three successive tasks.

The first task was to find the subsidence crater formed by the May 18, 1974 test. This task was undertaken not only to resolve the conflicting reports on the test location, but also to pinpoint the locale where subsequent nuclear testing activity allegedly took place. All of the Indian media reports on nuclear testing preparations in 1981, 1982, and 1995 described the location of the activity *relative* to the May 18, 1974 ground zero.[38] The crater formed by this test was found in the satellite imagery, which made it possible to attempt the second task—search for the existence of a nearby site reserved for future Indian nuclear tests.

Table 2: List of satellite images that were obtained, processed, and interpreted for the CTB verification exercise.

Satellite and Sensor	Ground Sample Distance[a]	Scene Center (Path-Row)	Acquisition Date and Time (GMT)	Relevance to Study
CORONA, KH-3	~10 m	27.17° N, 72.98° E	Dec 12, 1961	Oldest available image of Pokharan area acquired 13 years before India demonstrated a nuclear testing capability
Cosmos, KVR-1000	3-4 m	27.17° N, 71.80° E	May 24, 1992 03:26	High spatial resolution image of 1974 nuclear test site and surrounding area
SPOT-3, HRV-1 Panchromatic mode	10 m	26.98° N, 71.69° E 196-296	Mar 25, 1995 05:57:34	Most current, cloud-free image of Pokharan area acquired before the allegations of Indian nuclear test preparations were made
SPOT-3, HRV-1 Panchromatic mode	10 m	27.06° N, 71.76° E 197-295	Mar 2, 1996 06:02:29	Oldest, cloud-free image of Pokharan area acquired after the allegations of Indian nuclear test preparations were made
Radarsat, Synthetic Aperture Radar (SAR)	6.25 m	27.03° N, 71.80° E	Mar 6, 1996 13:22:35	Oldest, radar image of Pokharan area acquired after the allegations of Indian nuclear test preparations were made
SPOT-3, HRV-1 Panchromatic mode	10 m	27.11° N, 71.76° E 196-296	Mar 18, 1996 05:54:34	Stereo mate of March 2, 1996 SPOT image

a. — Ground sample distance (GSD) is the length and width of each pixel in a digital image projected onto the ground. Images captured on film are described at an equivalent GSD. The size of the GSD is a key factor in the amount of spatial detail in an image.

All of the media reports that described Indian nuclear test preparations claimed that the activity had taken place at a site reserved for nuclear testing. Even the two articles in the *Times of India* and *Jansatta* that strongly denied

Indian nuclear testing activity stated that such a site existed. The satellite images were analyzed in an attempt to either confirm or refute these claims of an Indian nuclear test site. This was done by interpreting the imaged features within the vicinity of the May 18, 1974 crater and comparing the image-derived information with the media reports. Digital change detection was also performed, which revealed new activity in the area. The third task was to determine whether the new activity could be attributed to recent conventional military exercises, nuclear test preparations, Prithvi field testing, or something completely different.

Locating the May 18, 1974 Subsidence Crater

Two archived satellite images were selected for use in the search for the May 18, 1974 subsidence crater. One image was acquired on March 25, 1995 by the HRV-1 panchromatic sensor on board the French SPOT-3 satellite. The other image was acquired on May 24, 1992 by the KVR-1000 camera flown on one of the Russian Cosmos satellites. The SPOT-3 image covered a 60 x 60 km area at a ten-meter ground sample distance. The KVR-1000 image covered a 40 x 40 km area at approximately four-meter ground sample distance.[39]

SPOT panchromatic imagery was chosen for the crater search because of its relatively large areal coverage at moderately fine spatial resolution. The March 25, 1995 image (Path 196, Row 296) was selected because it was the most current, cloud-free image in the SPOT archives that captured virtually all of the error circle associated with the ISC seismic location estimate of India's 1974 nuclear test (see figure 2).[40] The image also covered Pokharan town as well as the villages of Loharki, Khetolai, and Malka—all of the places that were reportedly near the May 18, 1974 explosion site.[41] In addition, the image contained the feature found in the October 26, 1988 IRS-1A image that was previously identified by one researcher as the crater formed by the nuclear test (see figure 1).

KVR-1000 imagery was chosen for the crater search because it was the highest resolution satellite imagery that could be bought on the open market. The May 24, 1992 image was selected because it was the only cloud-free image made available for purchase that captured a large portion of the error circle associated with the ISC seismic location estimate (see figure 2).[42] Like the SPOT image, the KVR-1000 scene covered the villages of Loharki, Khetolai, and Malka. It also contained five of the eight villages around Loharki that were reportedly planned for evacuation in 1981 (see figure 2).

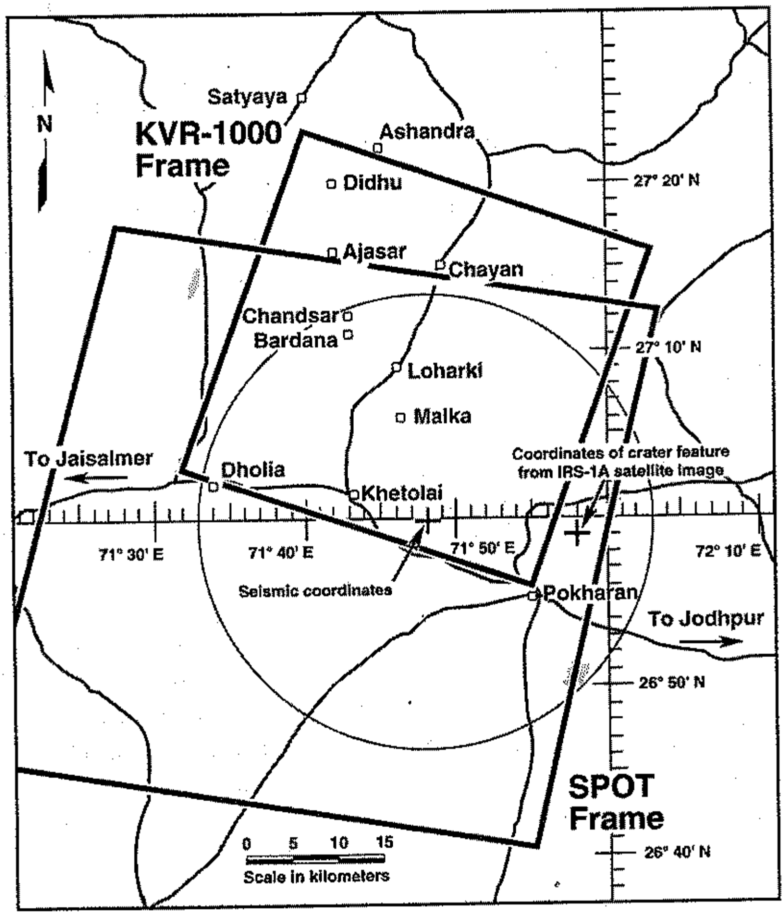

Figure 2: Geographic coverage of the archived March 25, 1995 SPOT image and May 24, 1992 KVR-1000 image. Both images cover large portions of the error circle associated with the ISC seismic location estimate of the May 18, 1974 test.

The full SPOT image showed flat terrain with agricultural fields bordering desert areas. Twenty-one towns and villages were located and identified in the image. The main rail line and the primary roads were also visible. However, no circular features were found that could be identified as the 18 May 1974 crater. The feature in the IRS-1A subscene was found in the SPOT image, but it still appeared too coarse to establish a conclusive match with the helicopter photo of the crater (see plates 1 and 2).

The KVR-1000 image consisted primarily of flat, desert terrain intermixed with sand dunes. Synoptic examination of this image revealed a large, circular depression located in a remote area about six kilometers south of Loharki.[43]

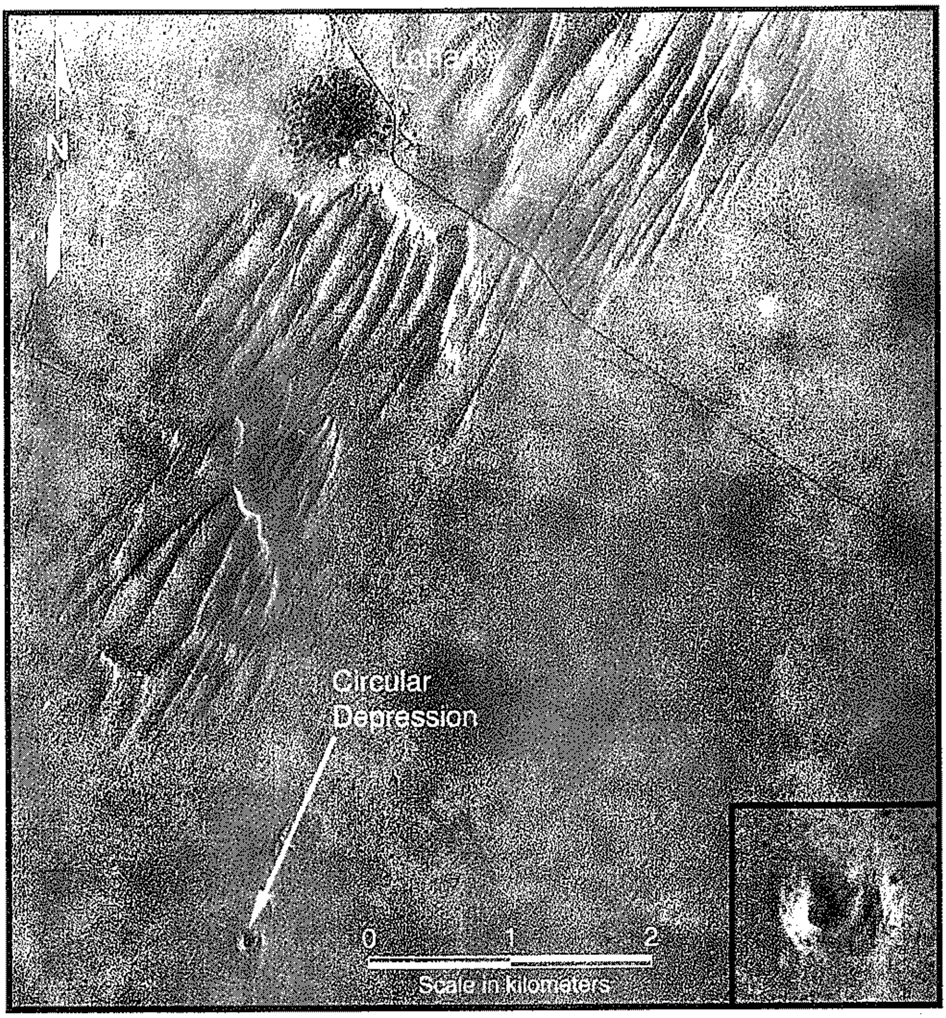

Plate 3: May 24, 1992 KVR-1000 image of a large circular depression located in relatively uniform desert terrain. The inset is an enlargement of the circular depression. The two, light-toned lines slanting across the image are scratch marks on the film positive.

Plate 3 shows the salient circular feature surrounded by the sandy desert terrain. The overhead view of the depression appeared similar to the May 18, 1974 crater shown in the helicopter photo. To determine whether the depression was indeed the subsidence crater, the KVR-1000 image was rendered as a

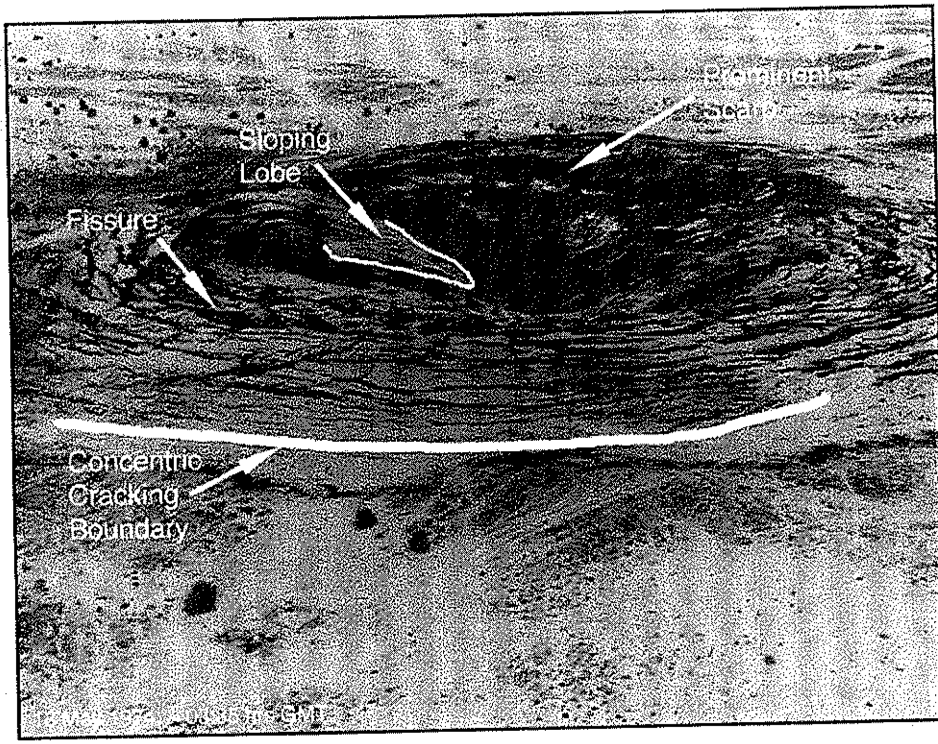

Plate 4: Annotated helicopter photo of the crater. The four physical features labeled on the photo were found in the KVR-1000 image of the crater (see plate 5). Note how the bushes in the foreground cast shadows toward the camera.

perspective view in order to replicate the oblique viewing angle of the aerial photo. By simulating the camera geometry that was used to acquire the aerial photo, the KVR-1000 perspective view of the depression could be compared directly with the helicopter photo of the crater. However, before the perspective view could be rendered, the bearing of the helicopter-borne camera had to be determined.

The helicopter photo was reportedly taken one hour after the explosion. According to the International Seismological Center (ISC), the explosion occurred at 02:34:55.40 ± .17 GMT so the photo must have been taken at approximately 03:35 hrs GMT on May 18, 1974.[44] At this instant in time, the sun was located east of the estimated test location and shadows pointed

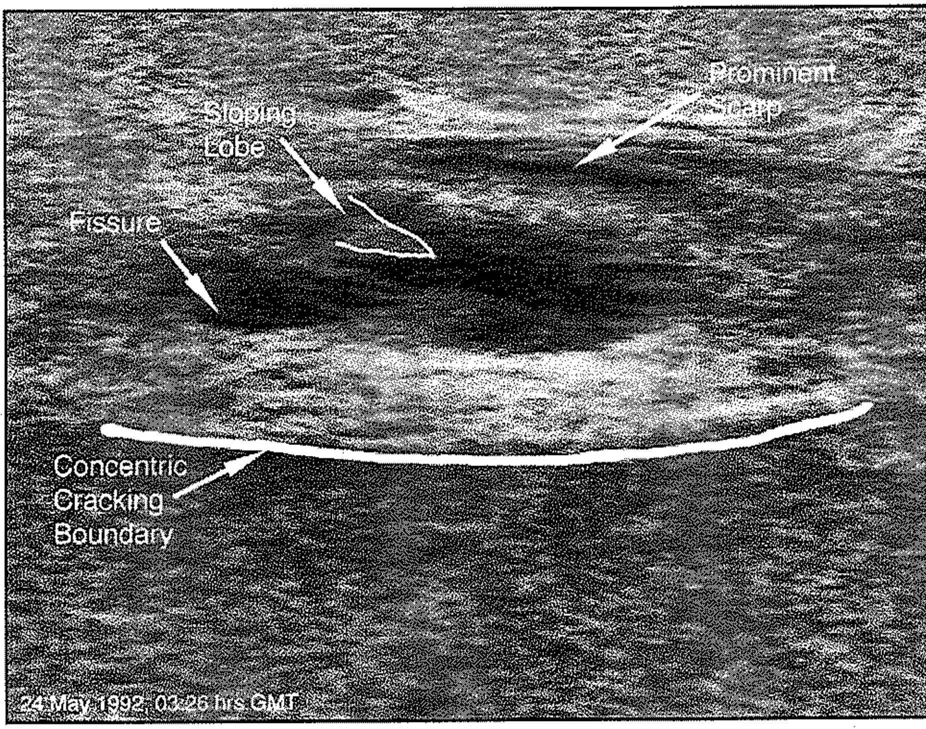

Plate 5: KVR-1000 perspective view of the large circular depression. The simulated aerial camera is located west of the crater and points to the east. The four physical features labeled in the image proved that the depression was the May 18, 1974 subsidence crater. The distance from the prominent scarp through the crater center to the concentric cracking boundary is 165 ± 2 meters.

towards the west (see Appendix A). In the foreground of the helicopter photo, the bush shadows point toward the camera providing a west compass bearing (see plate 4). Given this directional indicator, the helicopter-borne camera must have been positioned west of the crater and pointing east when the picture was taken.

Duplicating this camera orientation, the KVR-1000 image of the depression was rendered as a perspective view. The camera's elevation angle was approximated visually by distorting the circular depression into the oval crater shape shown in the helicopter photo. Fortuitously, the sun angle was also duplicated because the KVR-1000 image was acquired on almost the same

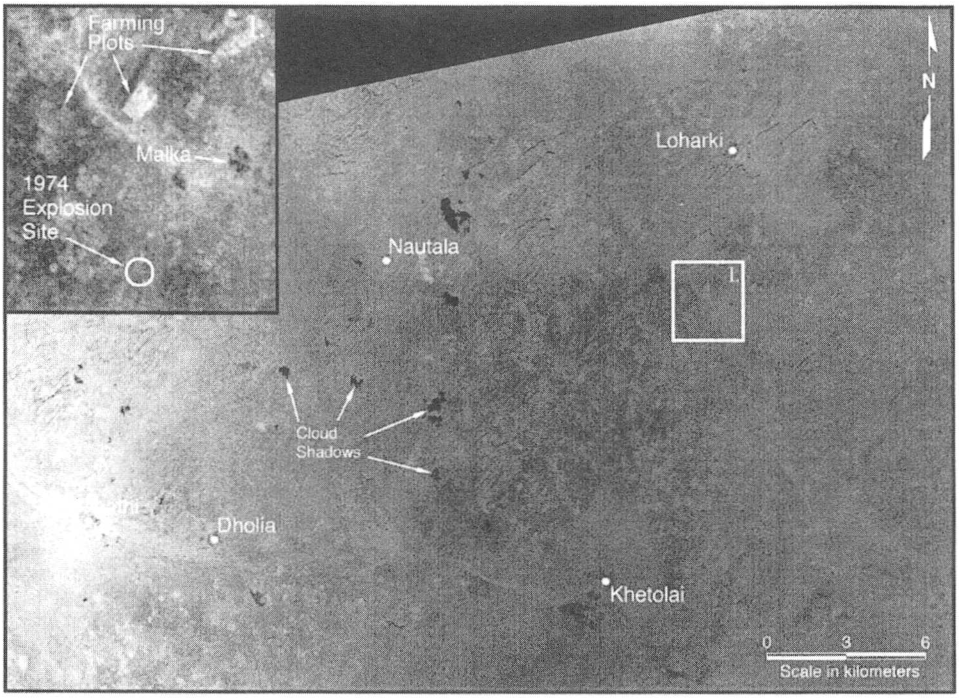

Plate 6: December 12, 1961 KH-3 image covering the 1974 nuclear test site and surrounding region. The small, light gray patches scattered throughout the image are farming plots. The black splotches on the image are cloud shadows. The inset is an enlargement of section I. showing Malka village and the exact area that was later used for the May 18, 1974 nuclear test.

date as the helicopter photo (May 24 ≈ May 18) at almost the exact same local time (03:26 hrs GMT ≈ 03:35 hrs GMT). As a result, the shading in the two images was virtually identical.

Comparison of the KVR-1000 perspective view with the helicopter photo revealed similar topographical features. These features proved to be the key for matching the two images. Four geomorphological structures from the circular depression were found in the helicopter photo, establishing conclusively that it was the subsidence crater formed 18 years earlier.[45] Plates 4 and 5 show the sloping lobe, scarp, fissure, and concentric cracking boundary that proved both images depicted the same crater.

After the circular depression was positively identified, its coarse outline was located in the March 25, 1995 SPOT image. The SPOT image was digitally merged with the two 1:250,000 scale maps of the area, and the geo-

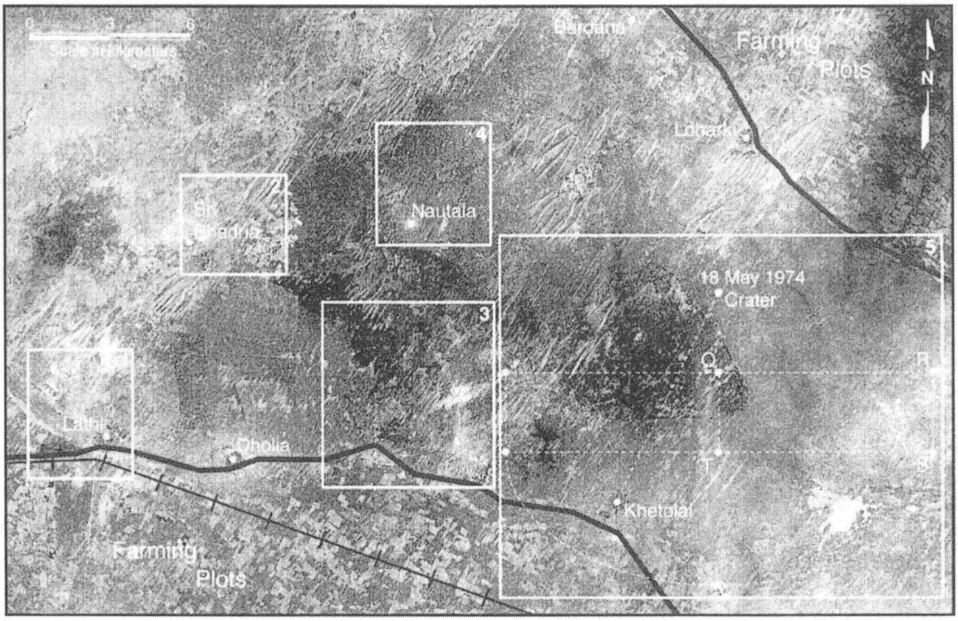

Plate 7: March 25, 1995 SPOT image covering approximately the same area shown in plate 6. Note the absence of polygonal farm plots over most of the land between the Khetolai-Dholia road and Loharki-Bardana road. Areas 1–5 contain features that appeared to relate to military activity. Area 5 contains all of the landmarks connected to alleged nuclear test activity in 1981, 1982, and 1995. Rectangle QRST represents the 8 km x 3 km fenced perimeter located three kilometers south of the 18 May 1974 crater, as described in the May 5, 1981 *Indian Express* issue. The perimeter was reportedly constructed in early 1981 shortly before Ajasar and Loharki village leaders were informed of a meeting on a four-day evacuation plan. Since the azimuthal orientation of the perimeter was not specified, the arc represents all of the possible perimeter orientations with the fence line at Q fixed three kilometers south of the 1974 crater.

The line connecting the May 18, 1974 crater and Khetolai represents the location of the area that was reportedly cordoned off by the Indian army and prepared for a nuclear test, as described in the May 9–15, 1982 issue of *Sunday Magazine*. The point on the May 18, 1974 crater represents the area where barbed wire fencing was reportedly erected in 1995, as described in the December 30, 1995 *Hindu* article, the January 1, 1996 *Business Standard* article, and the January 3, 1996 *Hindustan Times* article.

graphic location of the crater was measured: 27.095 ± .001° N, 71.752 ± .001° E.[46] That location placed the crater 1.5 km southwest of Malka village, 5.8 km south-southwest of Loharki village, 9.0 km north-northeast of Khetolai village, 24.8 km northwest of Pokharan town, 23.4 km west-northwest of the IRS-1A feature, and 12.5 km north-northwest (azimuth angle: 339°) of the ISC seismic location estimate for the May 18, 1974 test.[47] Thus, of the seven articles that reported the May 18, 1974 test location, only one—the May 9–15, 1982 *Sunday Magazine* article—accurately located it.

Searching for an Indian Nuclear Test Site

With the May 18, 1974 crater found, it became possible to determine whether the claims of an existing Indian nuclear test site were true. Since all of the media reports of nuclear test preparations in 1981, 1982, and 1995 locate the alleged activity within the vicinity of India's first nuclear test, the region surrounding the May 18, 1974 ground zero was analyzed to determine what kind of ordinary activity took place in the area and whether there were any abnormal features that could indicate the existence of a nuclear test site. To facilitate the analysis, a declassified KH-3 image was obtained (see plate 6).[48] Acquired on December 12, 1961, the image was the oldest one available of the area around the 1974 nuclear test site. Since it was acquired 13 years before India demonstrated its nuclear testing capability, it proved to be the ideal reference image. Comparison of recent satellite imagery with the historical KH-3 image revealed numerous changes throughout the landscape.

Plate 6 shows a small section of the KH-3 image strip that covered the 1974 nuclear test site and surrounding region. The image was acquired at approximately the same spatial resolution (10 meters) as SPOT imagery. Plate 7 shows a section of the March 25, 1995 SPOT image covering the same area. Both images show identical sand dune distributions, but appreciably different land use patterns. During the intervening 34 years, the Loharki-Bardana road and the Khetolai-Dholia road were paved and an east-west rail line through Lathi was constructed (see plate 7). In addition, Malka village ceased to exist and virtually all of the land between the two paved roads was taken out of farm production (see plates 3, 6, and 7).[49] Analysis of the March 25, 1995 SPOT image and May 24, 1992 KVR-1000 image revealed that much of this region had been taken over by the military. Features that appeared to relate to military activity were found in five distinct areas and subjected to closer examination (see plate 7).

At area 1, a feature shaped as a right triangle was located near Lathi (see plate 8). In contrast with the nearby agrarian lands, the triangular feature appeared dark in tone due the growth of natural, healthy vegetation in its interior. The presence of such vegetation was noteworthy because media reports described extensive livestock grazing in the area.[50] This feature, however, showed no signs of such agrarian activity which indicated that it was secured by perimeter fencing that kept wandering animals (and farmers) out. The sharp tonal contrast along the triangle's boundaries can be attributed to livestock grazing outside and up to the perimeter fence.

Inside the fenced area, the coarse outline of a facility can be seen. It is located next to the main road and rail line that lie along the hypotenuse of the right triangular perimeter (see plate 7). It is also located near a rail station

Plate 8: March 25, 1995 SPOT panchromatic image showing area 1 (see plate 7). Although the spatial resolution of the image is relatively low, it was possible to determine the functionality of several structures in the image by identifying distinct features and linking them together through deductive reasoning.

The image shows the coarse outline of a secured, military road-rail transfer station near a civilian rail station. Just north of the Khetolai-Dholia road and rail line, two rows of black dots off a single side road can be seen. These structures were inferred to be part of a military base.

south of Lathi village, which is indicated by the coarse outline of side tracks and buildings along the rail line connected to Lathi by a light-toned, well-trodden dirt road (see plate 8). Given its link to two primary transportation routes,

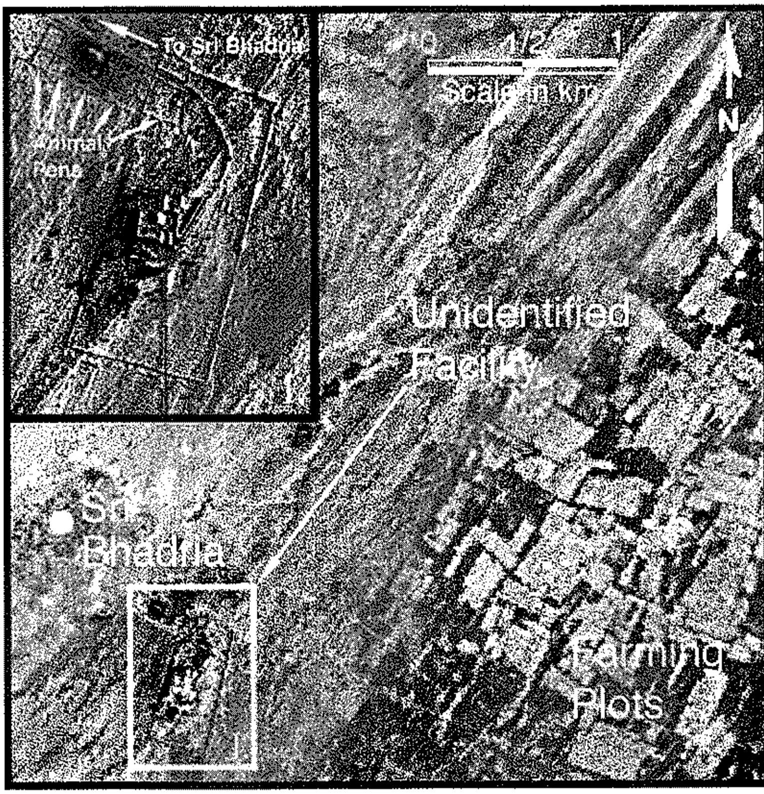

Plate 9: March 25, 1995 SPOT panchromatic image of area 2 (see plate 7). The image shows an unidentified, enclosed facility near Sri Bhadria. The inset of Section I. is the May 24, 1992 KVR-1000 image of the multistory facility showing several animal pens near the north-west perimeter.

the secured facility was inferred to be a military road-rail transfer point. The military role of the facility was deduced not only by the presence of the perimeter fencing, but also by the presence of the rail station south of Lathi. The existence of an unsecured and secured rail facility next to each other strongly suggested that the former was used primarily for civilian traffic and the latter was used principally for military transport purposes.

Just north of the military transport point, there is a site consisting of two rows of black dots with barren ground in between (see plate 8). These dots can be inferred to be large buildings similar in coarse appearance to the structures

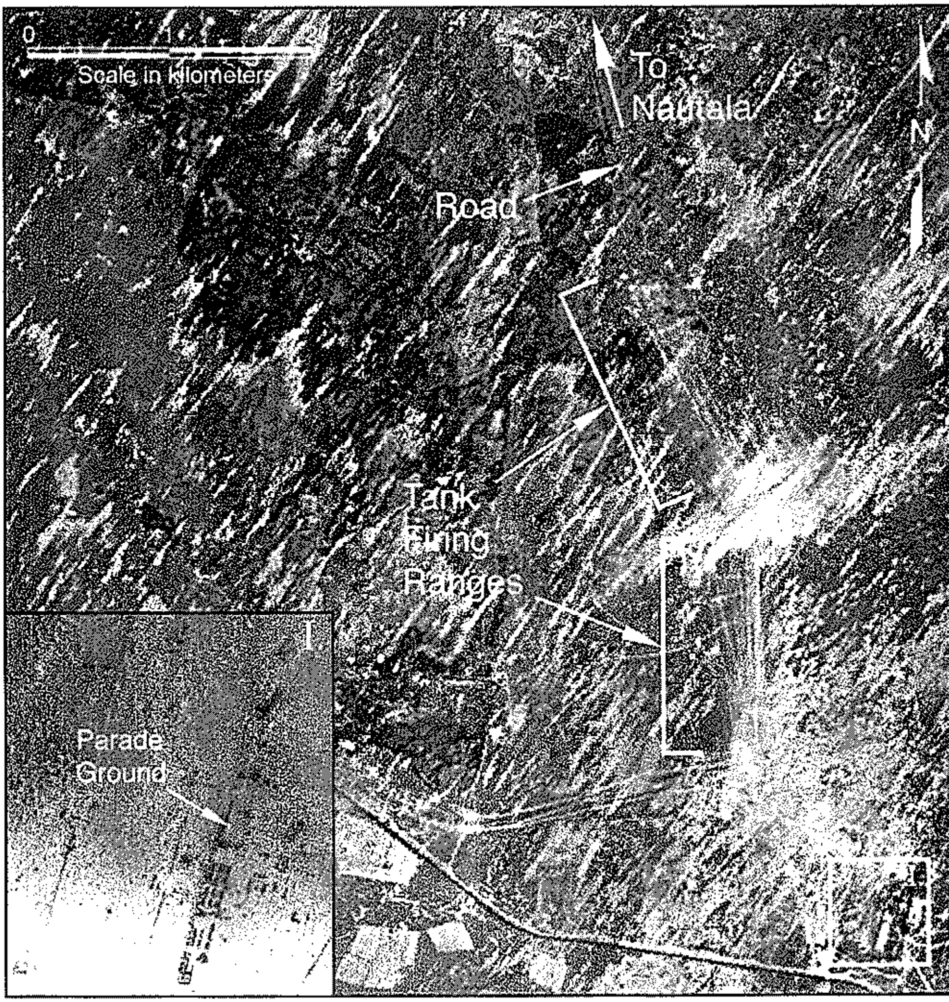

Plate 10: March 25, 1995 SPOT panchromatic image of area 3 (see plate 7). The image shows vehicle track patterns that are characteristic of tank firing ranges. The inset is the May 24, 1992 KVR-1000 image of the nearby complex linked by several roads to the firing ranges. This complex was inferred to be a military base consisting of Indian mechanized units.

shown in Lathi. However, in contrast with the structures in the village, the buildings in the remote site are widely spaced and distributed in an orderly fashion. In addition, the site can only be reached by taking a single, paved side road that ends at two large structures. Based on these site characteristics and its close proximity to the military transport point, the feature was inferred to be a military base.

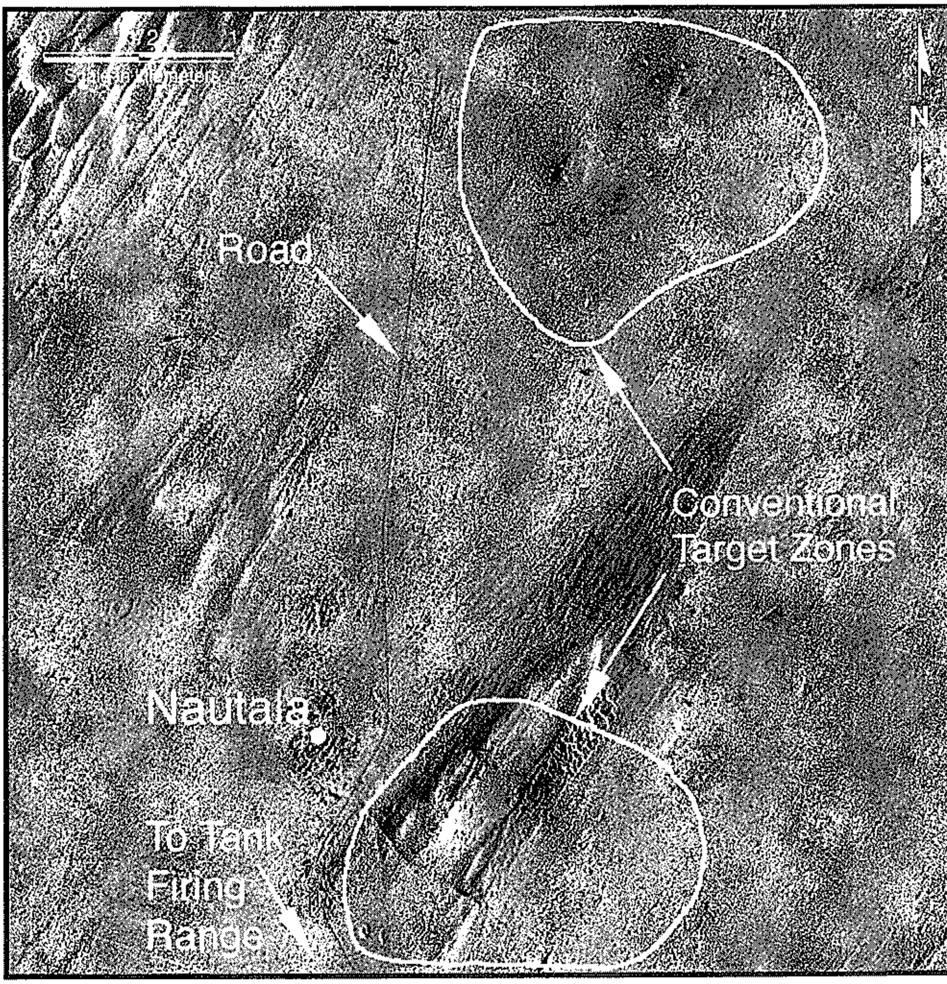

Plate 11: May 24, 1992 KVR-1000 panchromatic image of area 4 (see plate 7). The image shows two distinct zones littered with small craters. Both are located near the end of a paved road from the tank firing ranges and military base in area 3. These zones were identified as conventional target areas for artillery firing, aerial bombing, or both.

At area 2, a multistory, enclosed facility covering approximately 195,000 square meters was found near Sri Bhadria (see plate 9). It is located 0.5 km southeast of the village and 1.5 km west of the largest farming area between the Khetolai-Dholia road and Loharki-Bardana road (see plates 7 and 9). A single access road links the Sri Bhadria installation to the main road. To reach the facility, one has to travel on the Khetolai-Dholia road, turn onto the access

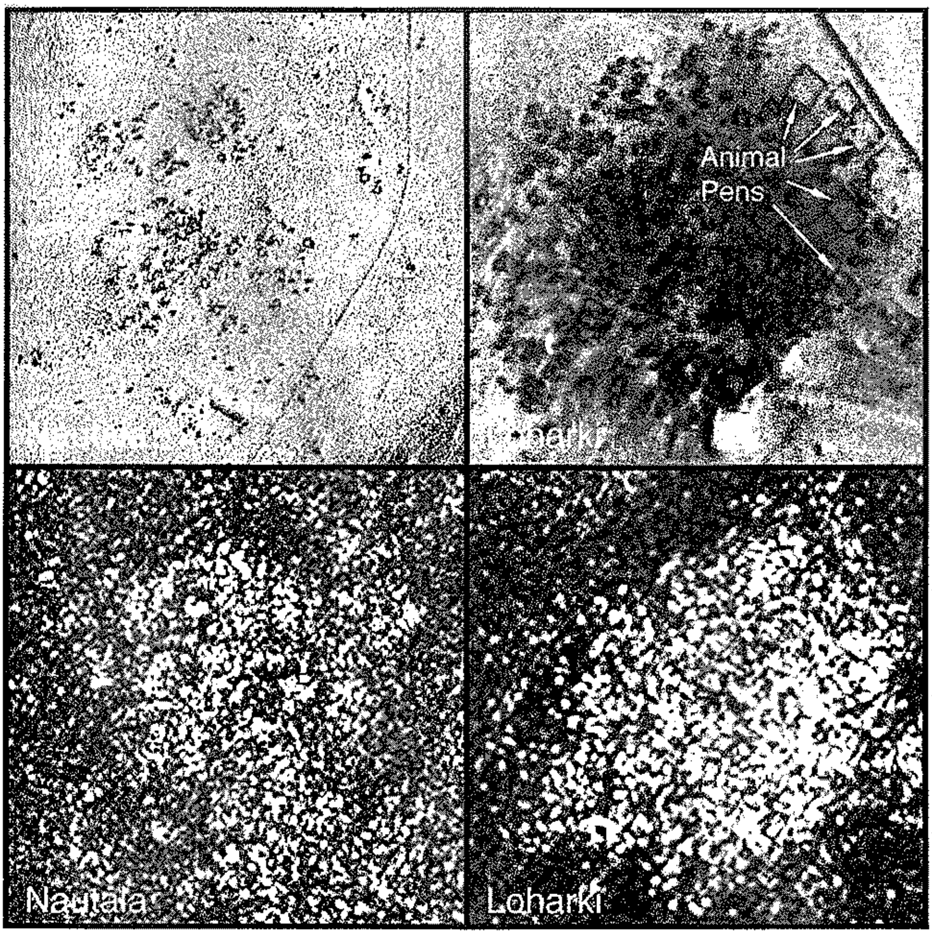

Plate 12: Panchromatic and radar images of Nautala and Loharki. The top two panels are sections from the May 24, 1992 KVR-1000 image. The bottom two panels are sections from the March 6, 1996 Radarsat image. The two KVR-1000 panels of each village were contrast enhanced using the same linear stretch algorithm. A different linear stretch algorithm was used for the two Radarsat panels.

road, and drive 8.3 km north through a fenced reservation.[51] Sri Bhadria can be reached by taking the single access road and driving through the facility (see plate 9).

The layout and architecture of the buildings provided little information on the functional purpose of the facility. Twelve animal pens located in the north-west corner of the perimeter were the only identifiable features (see plate 9 inset). These pens—along with the facility's close proximity to a large, isolated farming area—suggested that the facility may possibly be involved in agricultural activity. However, this did not explain definitively what kind of activities took place at the facility. As a result, the complex was left unidentified.

At area 3, two large, fanned sets of tracks were found just north of the Khetolai-Dholia road (see plate 10). The scale, tone, and texture of these converging tracks is identical in overhead appearance to published SPOT images of known tank firing ranges in former East Germany.[52] The appearance also matches a veteran photointerpreter's description of tank firing ranges worldwide.[53] Based on these references, the converging tracks shown in plate 10 were identified as tank firing ranges.[54] The firing ranges are connected by several roads to a large complex located just off the Khetolai-Dholia road (see plate 10 inset). In contrast with the village layouts, the complex consists of numerous columns of buildings and a parade ground. Given its configuration and proximity to the firing ranges, it was inferred to be a military base consisting of Indian mechanized units.

At area 4, two sandy zones littered with numerous, small pockmarks were located in the May 24, 1992 KVR-1000 image (see plate 11). Both zones are located at the end of a paved road from the tank firing ranges and military base in area 3. One crater zone is located 0.8 km east of Nautala and the other is located 2.25 km northeast of the village. Virtually all of the craters are approximately 15 meters in diameter.[55] The village itself appeared to be in a dilapidated state. In contrast with nearby Loharki village, the rooftops at Nautala did not form enclosed polygons, suggesting that the roof structures were incomplete (see plate 12). Also, no animal pens were present at Nautala. The March 6, 1996 Radarsat image also showed differences between the two villages. When Radarsat imaged Loharki village, it produced a strong radar return. In contrast, Nautala produced a weak radar return, suggesting the absence of standing structures capable of acting as corner reflectors (see plate 12). All of this evidence led to the conclusion that Nautala village had been abandoned.[56] Thus, the two cratering zones near the uninhabited village must be conventional target areas for artillery shelling, air bombardment, or both.[57]

At area 5, the terrain was searched for features and activity that could relate to nuclear testing. The boundaries of area 5 surround the geographic region where nuclear test preparations reportedly took place in 1981, 1982, and 1995 (see plate 7). Visual analysis of this area in the March 25, 1995 SPOT image and May 24, 1992 KVR-1000 image revealed a large, triangular-shaped perimeter with unpaved roads, buildings, and berms located inside (see plate 13). The base and height of the isosceles triangle are 5.7 km and 6.1 km respectively. Two sides of the triangular perimeter are clearly delineated by the dark-toned vegetation on the inside and barren, sandy terrain on the outside. Like the perimeter around the military road-rail transport station in area 1, the sharp tonal contrast can be attributed to the livestock that reportedly graze in and around the May 18, 1974 crater.[58] The western side of the triangular perimeter was not easily visible from the differential vegetation, but it was discernible in the high-resolution KVR-1000 image. As shown in plate 13, the center of the triangular perimeter is located 3.3 km southwest of the May 18, 1974 crater. The location of the secured area matched the May 9–15, 1982 *Sunday Magazine* report, which described a cordoned area between the May 18, 1974 crater and Khetolai that was allegedly prepared for a nuclear test (see plates 7 and 13). The secured area also overlapped the 8 km x 3 km perimeter described in the May 5, 1981 *Indian Express* article that was constructed shortly before two village leaders were reportedly informed of an official meeting on a four-day evacuation plan (see plates 7 and 13).[59]

Roads intersect the perimeter at four different points indicating several portals for entry and exit. The portals are located along the north, northeast, east, and south perimeter. The south portal appears to be the principal transportation point to and from the secured area as it is closest to the main road. To reach it from the Khetolai-Dholia road, one has to turn off the main road, drive north through the military base at area 3, and then proceed 4.0 km northeast to the south entrance.[60] Once there, one can drive around the entire site along the inner perimeter road passing by a south perimeter base and an east perimeter base (see plate 13 insets).

Deeper inside the perimeter, there are two discernible areas with unpaved roads leading to sites cleared of vegetation. The May 24, 1992 KVR-1000 image shows the easternmost site located next to a berm (see plate 13 inset). No distinct features can be resolved here. Near the center of the triangular area, there are four large sites enclosed by berms or fencing as well as several small site encircled by berms. Several buildings are located within each site and there is an enclosing berm opposite a single access road (see plate 14).

Area 5 has all of the appearances of a military test range. It is located in a remote area with open space inside and outside the fenced perimeter. It contains infrastructure, a road network, several berms, and a limited number of portals into the secured area. In addition, it is linked by road to a military armor base with two conventional testing areas. All of these features make area 5 suitable for a variety of military exercises and weapons tests. And since this area was used for the May 18, 1974 nuclear test and has been the geographic focal point of subsequent allegations of nuclear test preparations, future nuclear testing could be one of the purposes for area 5. With that possibility in mind, area 5 was designated the Khetolai military range and tentatively considered a potential Indian nuclear test site until more recent imagery could be analyzed to establish its purpose in a more definitive way.

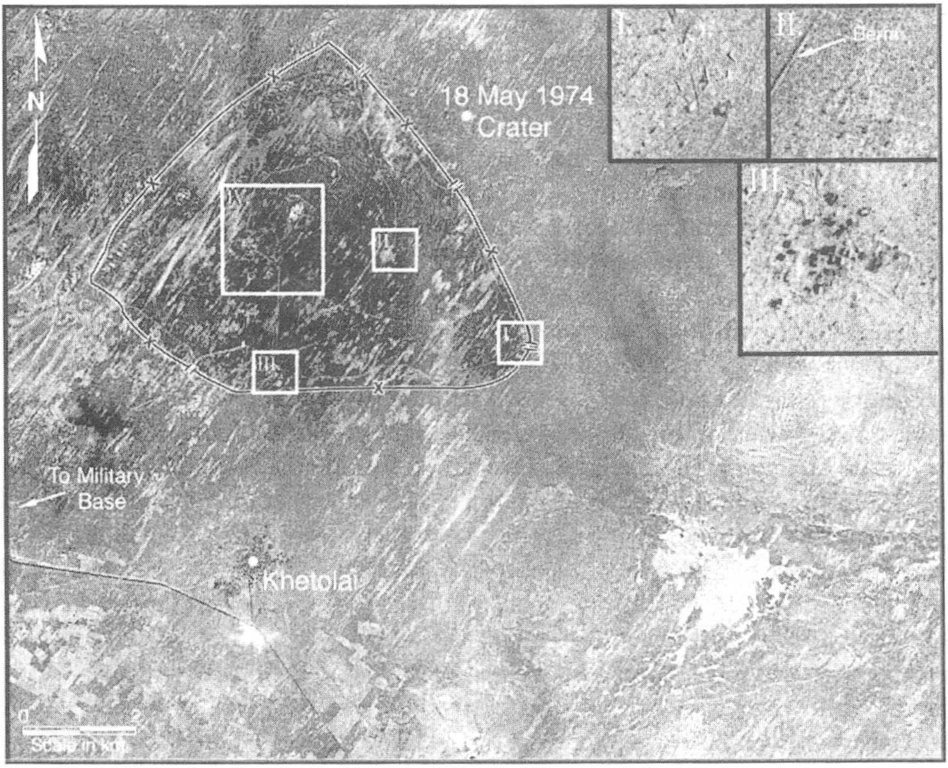

Plate 13: March 25, 1995 SPOT image of area 5 (see plate 7). The image shows a large, triangular perimeter with a network of roads inside. The insets are May 24, 1992 KVR-1000 sections showing large buildings and structures inside the perimeter located at areas that have been cleared of vegetation.

Detecting Changes at the Military Areas near Khetolai Village

On March 2, 1996, the French SPOT-3 satellite acquired a cloud-free panchromatic image of the Pokharan area. The image was acquired almost three months after the initial allegations of Indian nuclear test preparations were made. Four days later during its engineering test phase, the Canadian Radarsat acquired a fine beam radar image of the same area, which was obtained as a single look image at a 6.25 meter ground sample distance. On March 18, 1996, the French SPOT-3 satellite acquired a cloud-free stereo mate of the 2 March 1996 panchromatic image. All three images were analyzed for recent activity at the military areas near Khetolai.

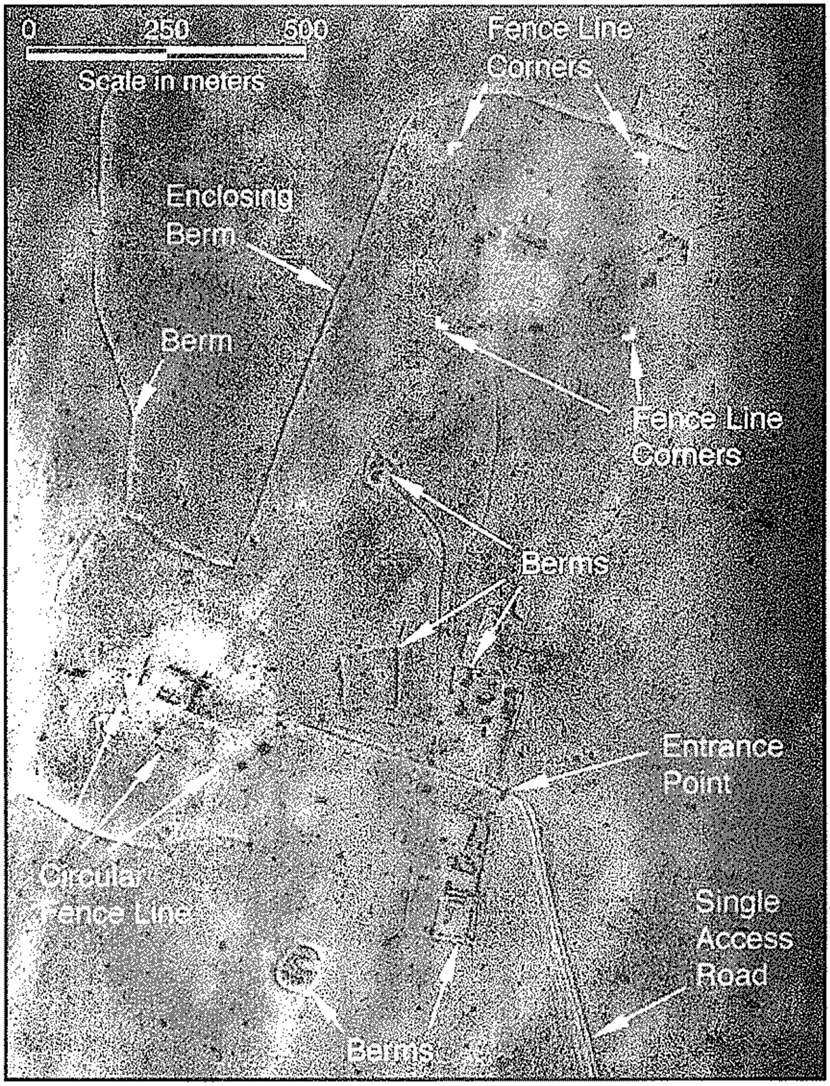

Plate 14: May 24, 1992 KVR-1000 image of section IV. from plate 13 merged with the 25 March 1995 SPOT image. The merge was done by laying the two images over each other (geometric registration) and adding the two together (digital summation). The cleared areas shown in the March 25, 1995 SPOT image overlap four large sites with buildings that can be reached from a single access road. There is an enclosing berm opposite the single access road, and there are berms or fences surrounding all of the sites. The light-toned, horizontal lines that cross the entire image are scratch marks on the KVR-1000 film positive.

The 1996 SPOT images were interpreted first in stereo following contrast and edge enhancement.[61] Besides the stabilized sand dunes scattered throughout the image, no other mounds of sand and earth were found. This suggested that either the *Hindu* and *Hindustan Times* reports of a new hill in the area were incorrect, or the hill was removed before the 1996 SPOT images were acquired. It is also possible that the pile of earth was imaged by SPOT-3, but the height differential was too small to be detected in the stereo pair.[62]

Following the stereo analysis, the 1996 SPOT images were registered to the 1995 SPOT image using a second-order polynomial and nearest neighbor resampling. The old and new images were then rendered as a time-lapse, repeating sequence showing landscape changes as small as one 10 m x 10 m pixel. In all three military areas near Khetolai, the time-lapse sequence revealed substantial change between March 25, 1995 and March 2, 1996 and little change between March 2, 1996 and March 18, 1996.[63]

Plate 15 is a section of the March 18, 1996 SPOT image showing the large-scale changes that occurred over the one year period. The most conspicuous change is a large area denuded of vegetation inside the security perimeter at the Khetolai military range (see plate 15 inset). The light-toned area covers approximately 1.6 sq km and is visible in both 1996 SPOT images. Shaped as a plume with two point sources, it extends past a berm ending at an unpaved road. The denuded area exhibits the characteristic effects of a brush fire.[64] At an unknown date and time after the SPOT image acquisition on 25 March 1995, two fires must have started at the point sources, spread downwind over the berm, and stopped at the unpaved road which acted as a fire break. The light-toned appearance of the burnt area can be attributed to the sunlight reflectance off the sandy soil that was previously covered with vegetation.

Besides the fire damage, new vehicle tracks were detected in the tank firing ranges and the Nautala target area. Several new vehicle tracks were observed connecting the Nautala target area to the Khetolai military range (see plate 15). No road traverses the sandy terrain between these two areas so the tread marks must have been produced by four-wheel drive or tracked vehicles. At the northern perimeter of the Khetolai military range, the tracks divide into three sets. One set connects to the north portal, indicating vehicle traffic between the Nautala target area and the secured areas inside the Khetolai military range (see plate 15 inset). Another set indicates direct vehicle traffic between the Nautala target area and the area around the May 18, 1974

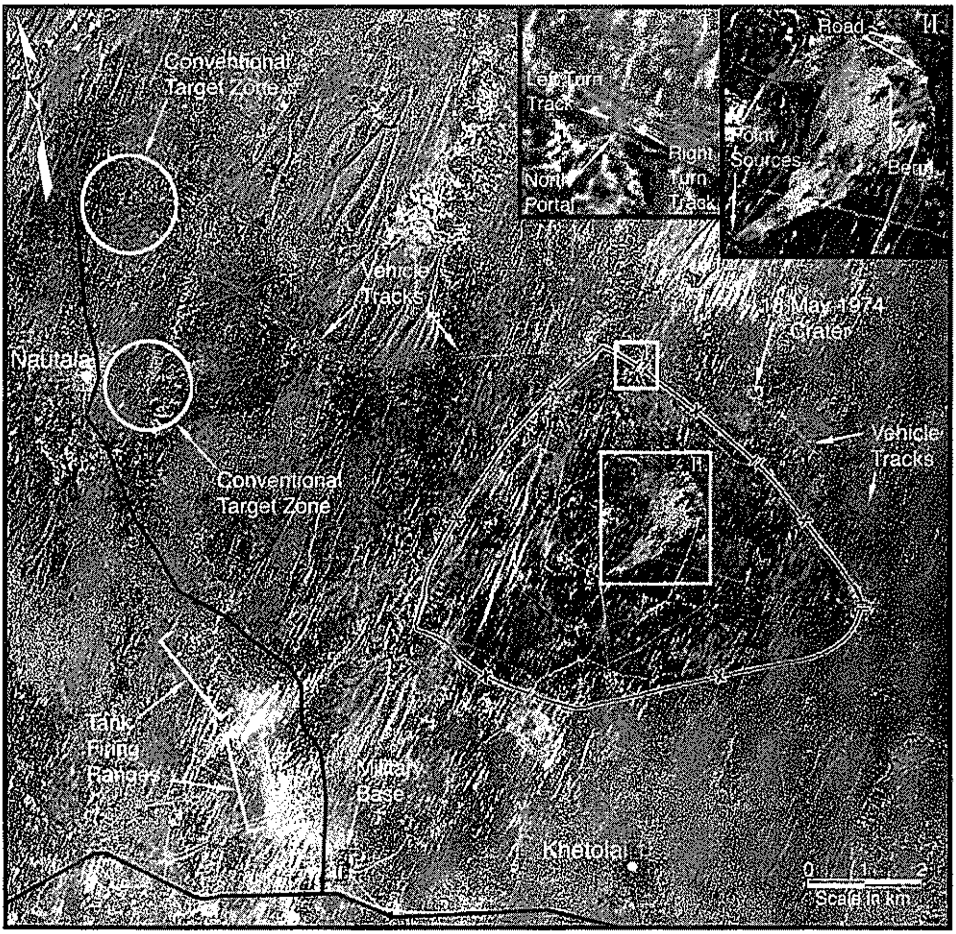

Plate 15: March 18, 1996 SPOT image showing the tank firing ranges, the Nautala target areas, and the Khetolai military range. The vehicle tracks identified in this image were not present in the March 25, 1995 SPOT image, which means the surface markings were less than one year old. Section I. shows the left and right turn tracks at the north portal of the Khetolai military range. These turns indicate vehicle traffic between the Nautala target area and sites inside the secured perimeter as well as traffic between the May 18, 1974 crater and the inner area. Section II. shows the damage caused by two brush fires that occurred inside the fenced perimeter. The cause and exact date of each fire could not be determined from the imagery.

crater. The third set of tracks indicate vehicle traffic between the secured areas inside the Khetolai military range and the area around the 1974 subsidence crater.

Plate 16 shows the series of new vehicle tracks converging at an area next to the 1974 crater and proceeding towards the southeast. It also shows a ring around the subsidence crater that was not present in the March 25, 1995

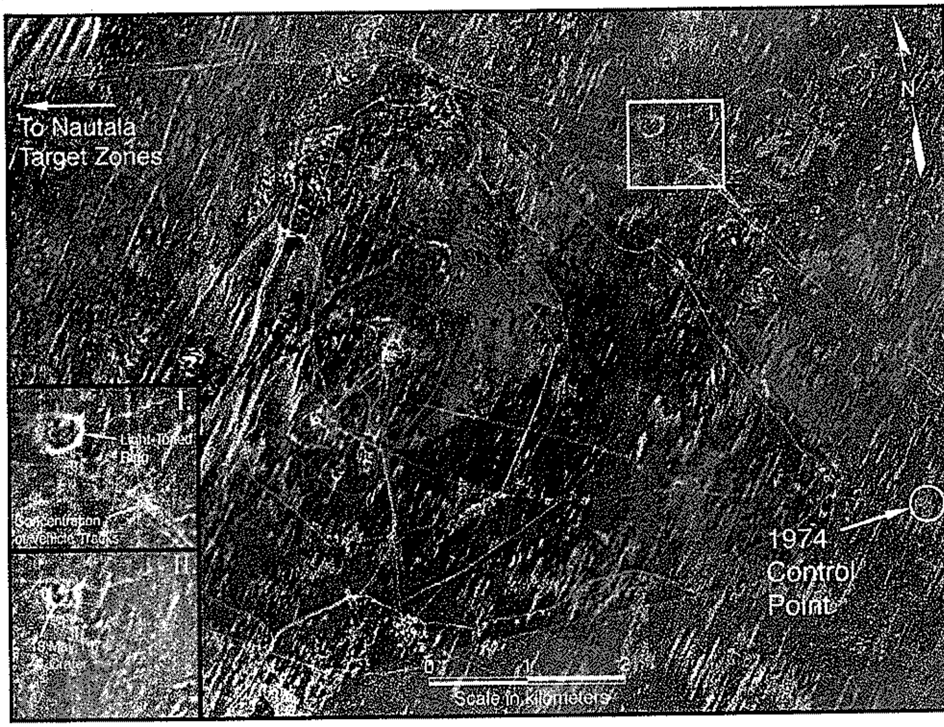

Plate 16: March 2, 1996 SPOT image of the Khetolai military range. The image shows new vehicle tracks around the 1974 subsidence crater proceeding towards the southeast. The 1974 control point location was mapped onto the image (see Appendix B).

Section I. shows how the area around the May 18, 1974 crater looked on March 2, 1996 and Section II. shows the same area almost one year earlier on March 25, 1995. Comparison of the two insets revealed a new, light-toned ring around the crater and a nearby concentration of vehicle tracks.

SPOT image (see plate 16 insets). These changes around the old nuclear test site prompted a reexamination of the published ground and aerial photos that were acquired at the time the first Indian nuclear test was conducted.[65] The historical pictures were analyzed for topographic clues that could help explain why there was renewed activity around the old nuclear test site. The analysis of the archived information did not provide a conclusive answer. However, it did reveal the location of the control point for the May 18, 1974 test (see Appendix B and plate 16).

Inside the fenced perimeter of the Khetolai military range, other new activity was observed. Plates 17 and 18 show how the secured area changed between the March 25, 1995 and March 2, 1996 SPOT-3 image acquisitions. Comparison of the two images revealed two, new concentric sets of curved traces that enclose all sites located in the center of the military range. A new linear trace was also seen intersecting both sets of curved features. The trace lies perpendicular to the prevailing southwest-northeast wind direction, which is indicated by the orientation of the nearby sand dunes (see plate 17).[66]

From point E to point G, it is 2.1 km in length (see plate 18). At one end, it goes through an existing road connecting to point G. At the other end, it branches out in four separate directions passing through at least one established berm or fence and ending at sites A–D in the center of the military range (see plates 18 and 19). Relative to the adjacent land, sites A–D appear slightly larger and brighter in the time-lapse sequence. This ground scarring can be attributed to increased activity at the sites over a one year period.[67]

All of the new features that were found in the 1996 SPOT images were then checked in the March 6, 1996 Radarsat image. The radar image was analyzed to gather information on the surface structure and metallic composition of the new man-made features. In arid regions, these two traits are typically the dominant factors that determine the magnitude of the radar return.[68] If the illuminated objects act as corner reflectors or electrical conductors, the microwave reflectance will be higher than the surrounding background. Conversely, features with flat surface profiles or low conductivity either appear darker than the background or are indistinguishable from the surrounding environment.

Radarsat imaged the three military ranges around Khetolai at a 43°–46° incidence angle relative to nadir (i.e., straight down) pointing towards the east-northeast. The synthetic aperture radar (SAR) operated in the C-Band (5.6 cm). In contrast with the panchromatic visible images, the SAR image appears speckly due to the random interference of the coherent waveforms (see plate 20).[69] Despite its grainy appearance, the SAR image shows a relatively strong radar return from buildings, berms, and fence lines identified in the KVR-1000 image as well as a barely discernible radar return from fence lines delineated in the SPOT images by the differential vegetation. Segments of these identified features positioned perpendicular to the incident microwave beam produced the strongest relative radar return. Similarly oriented segments of the curved traces in the 1996 SPOT images were also seen in the SAR image, including a faint circular arc inside the new light-toned ring around the 1974 subsidence crater (see plate 20).[70] None of the new linear traces or vehicle tracks were detected in the Radarsat image, suggesting the absence of structures or conductive materials.

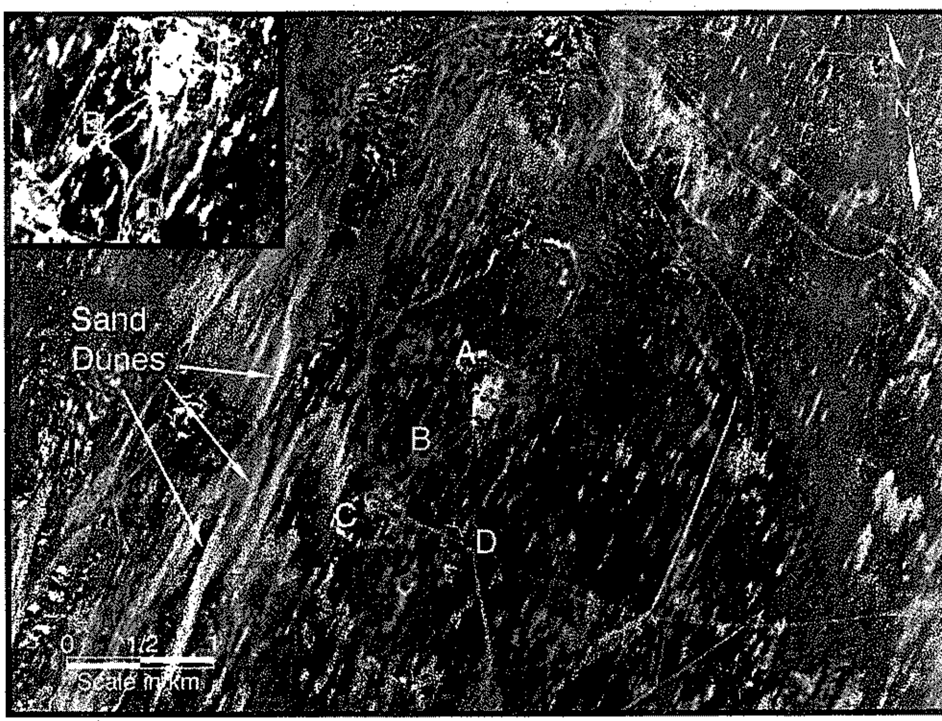

Plate 17: March 25, 1995 SPOT image of the secured area inside the Khetolai military range. The sand dunes lie along the southwest-northeast axis of the prevailing wind flow. The inset is a contrast enhanced enlargement of sites A-D covering the same area depicted in the plate 18 inset.

The segments of the curved traces that were observed in the SAR image had radar signatures that were similar to the known berms and fence lines in the area. And since these features completely surround specific sites, it was reasonable to deduce that the curved traces were new perimeter barriers. Between March 25, 1995 and March 2, 1996, these barriers were constructed around the centrally located sites within the Khetolai military range. An additional barrier was built around the 1974 subsidence crater, which must be the new fence described in the *Business Standard*, *Hindu*, and *Hindustan Times* articles.

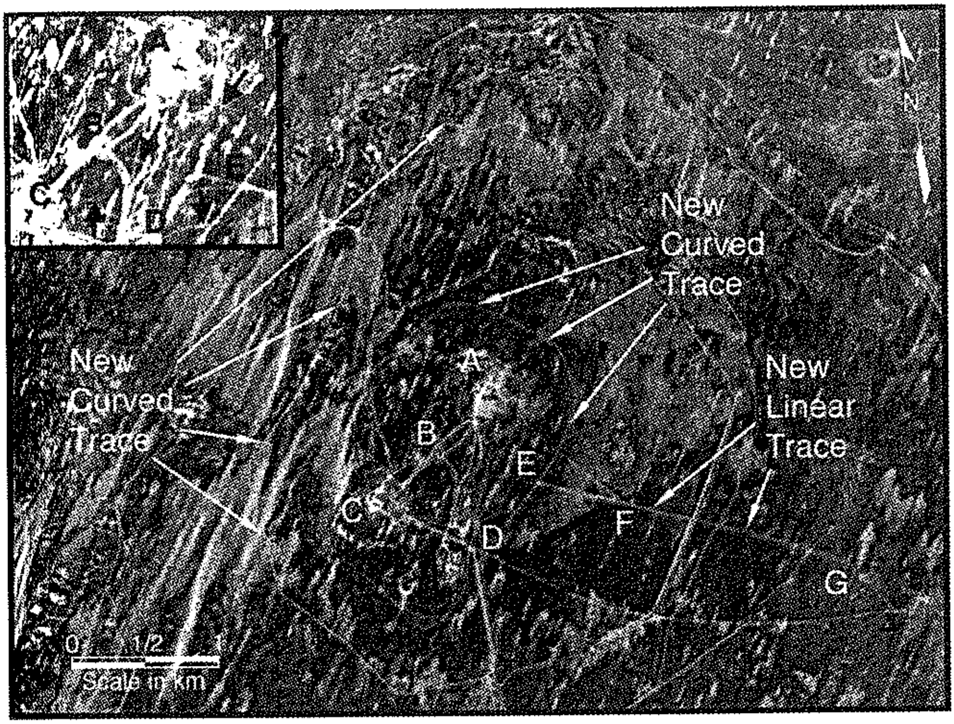

Plate 18: March 2, 1996 SPOT image of the secured area inside the Khetolai military range. The image covers the same area shown in plate 17. It shows new linear and curved traces that were constructed over a one year period. Line EG lies perpendicular to the sand dunes, which point in the direction of the prevailing southwest-northeast winds. Points A–G are the endpoints of the new linear features. The inset is a contrast enhanced enlargement of sites A–D pointing out four linear traces that branch off line EG. These traces were not present in the SPOT image acquired one year earlier (see plate 17 inset).

Interpreting the Activity at the Khetolai Military Range

The image-derived information conclusively established three facts. First, between March 1995 and March 1996, substantial activity did take place at the Khetolai military range in the immediate vicinity of the 1974 nuclear explosion site. Compared with the changes at the nearby tank firing ranges and the conventional target areas at Nautala, the activity at the Khetolai military range left the most and the largest "footprints" on the ground. Second, this activity involved the military. This was evident because the detected changes happened within established military ranges and consisted of perimeter reinforcement, all terrain vehicle traffic, and extensive ground clearing. Third, the observed activity was different in scale and appearance from activities that had taken place in the recent past. The May 24, 1992 KVR-1000

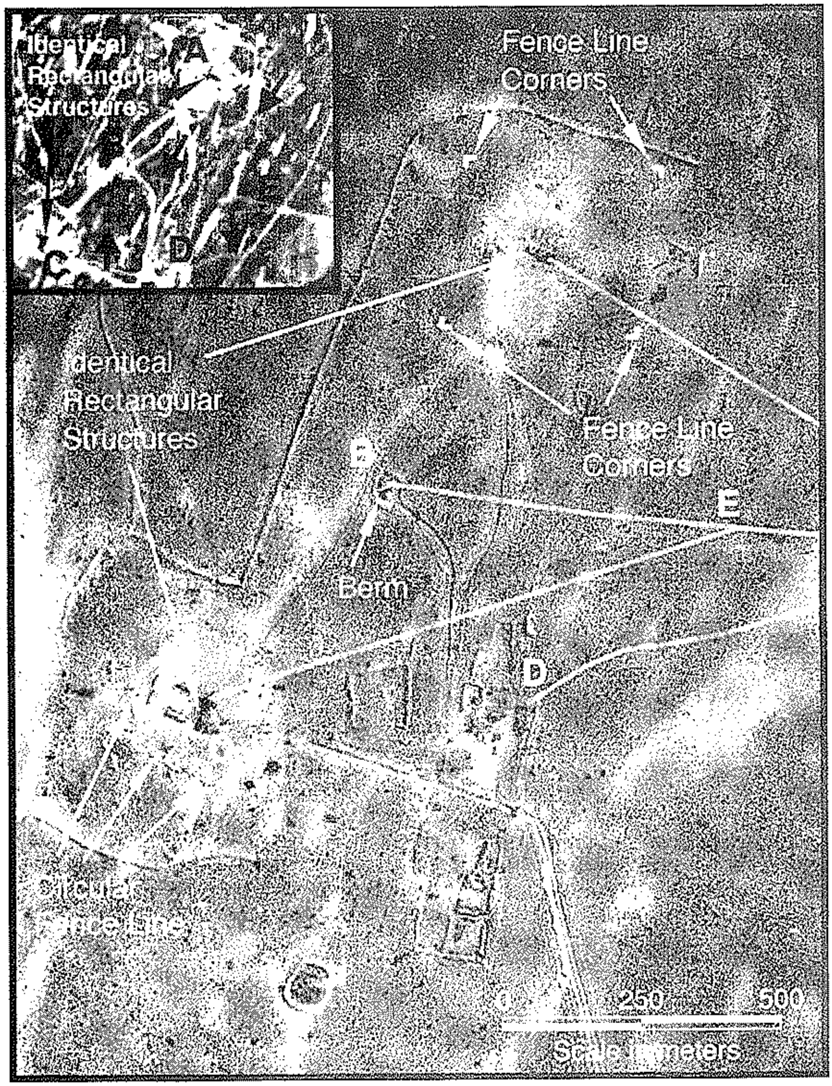

Plate 19: March 18, 1996 SPOT image of sites A-E merged with the May 24, 1992 KVR-1000 image. The merge was done by laying the two images over each other (geometric registration) and adding the two together (digital summation). The linear traces shown in the March 2, 1996 SPOT inset were mapped onto the image. At sites A–C, the traces end at the center of the secured perimeters. At sites A and C, the linear traces intersect the same edge of identical rectangular structures that are visible in the KVR-1000 image. The coarse outline of these two structures are visible in the March 2, 1996 SPOT inset and plate 20.

image and the March 25, 1995 SPOT image indicated that no large-scale changes took place at the Khetolai military range over the three year period. Furthermore, neither image shows vehicle track patterns from the 1991 and

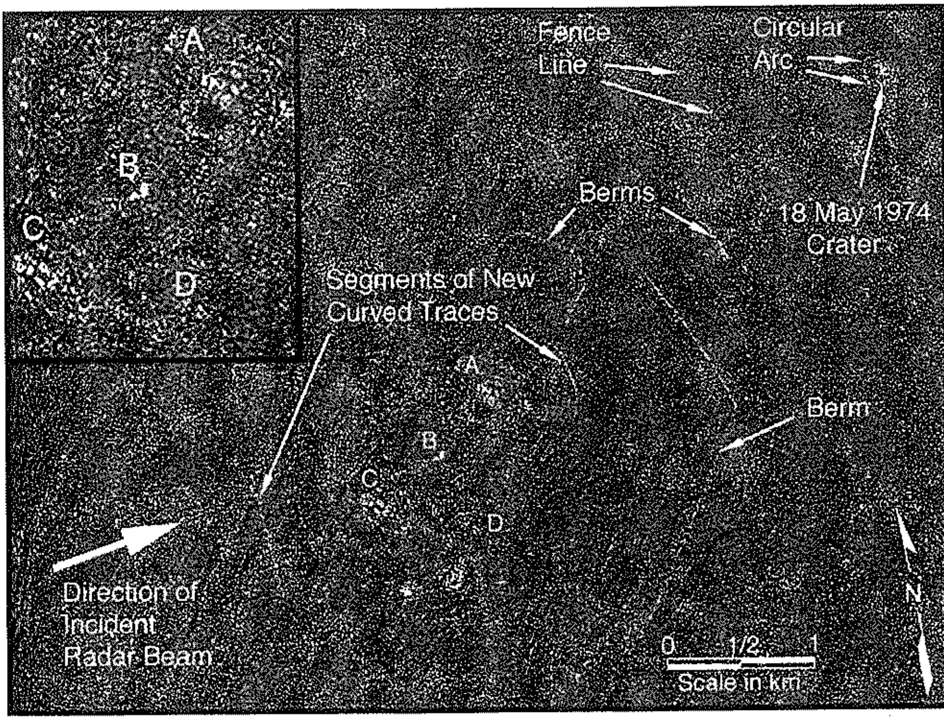

Plate 20: March 6, 1996 Radarsat image of the secured area inside the Khetolai military range. The image covers the same area shown in plates 17 and 18. Although the SAR image appears speckly, it shows the coarse outline of known buildings, berms, and fence lines. It also shows segments of the curved traces around sites A–D and the 1974 subsidence crater that were oriented perpendicular to the incident radar beam. These curved traces were identified as new perimeter barriers. The inset is an enlargement of the central sites showing strong radar returns from the buildings and structures in sites A–C and weak microwave reflections from the fence lines around sites A and C.

1994 winter military exercises that resemble the track patterns in the 1996 SPOT images, which were acquired three months after the 1995 winter exercises.

With these three facts in mind, the image-derived information was integrated into the body of evidence. The collection of claims and facts were sifted and organized into groups in order to determine whether the observed large-scale, unusual activity could be attributed to conventional exercises, nuclear test preparations, Prithvi field testing, or something completely different. This was done in three steps.

The first step was a credibility assessment of each media report through comparison with the image-derived information. If a specific factual claim in a news article was corroborated or consistent with the image-derived information, it was assigned a '+' indicator. If the claim was inconsistent with the imagery, it was assigned a '–' indicator. If a factual statement was checked with overhead imagery and the result was inconclusive, it was given a '•' indicator. Other articles that could be linked to these factual claims were also assigned the corresponding indicators. The total number of the three indicators for each article provided a semi-quantitative way of assessing the believability of other factual claims in the article that could not—for purely technical reasons—be checked with the available commercial satellite imagery. If an article contained several verified facts, the other reported facts were deemed as believable. If an article contained numerous false or inconsistent statements, the remaining claims were not considered credible.

Appendix C illustrates how this credibility assessment was done and tabulates the results for each news report that described activity (or inactivity) in the Pokharan area. Media reports with at least one factual claim that was consistent with the image-derived information were classified as minimally credible and were used as evidence for identifying the activity at the Khetolai military range. Articles that could not be linked to any substantiated facts were excluded from the analysis. Articles with factual claims that could not be geographically linked to the Khetolai military range were also set aside.

The second step was an examination of each remaining item of evidence to determine whether it could be attributed to conventional, missile, nuclear, or innocuous activity at the Khetolai military range. This was done by researching the hallmark and peripheral signatures of these four activities and comparing the evidence with these signatures. A table of suppositions was compiled to determine whether each set of evidence could be logically attributed to at least one of the four activities (see Appendix D).[71] This table outlines the various plausible explanations for the evidence.

The third step involved the placement of the evidence onto a Venn diagram. A Venn diagram is a logic tool consisting of overlapping circles that represent different sets and the relationships between them.[72] In this case, each circle represented a different explanation for the activity at the Khetolai military range (see figure 3). If an item of evidence could be best explained by just one of the four activities, it was placed inside the corresponding circle and outside the other circles. If it could plausibly be attributed to more than one activity, it was placed into the appropriate overlapping area demarcated by the representative circles.

Analyzing the Venn Diagram of the Khetolai Military Range

Figure 3 shows the Venn diagram that was produced from the evidence and suppositions listed in Appendices C and D. Spatially linked items of evidence were connected together with a solid line, and evidence that could be spatially related were connected with dashed lines. In addition, since the diagram was

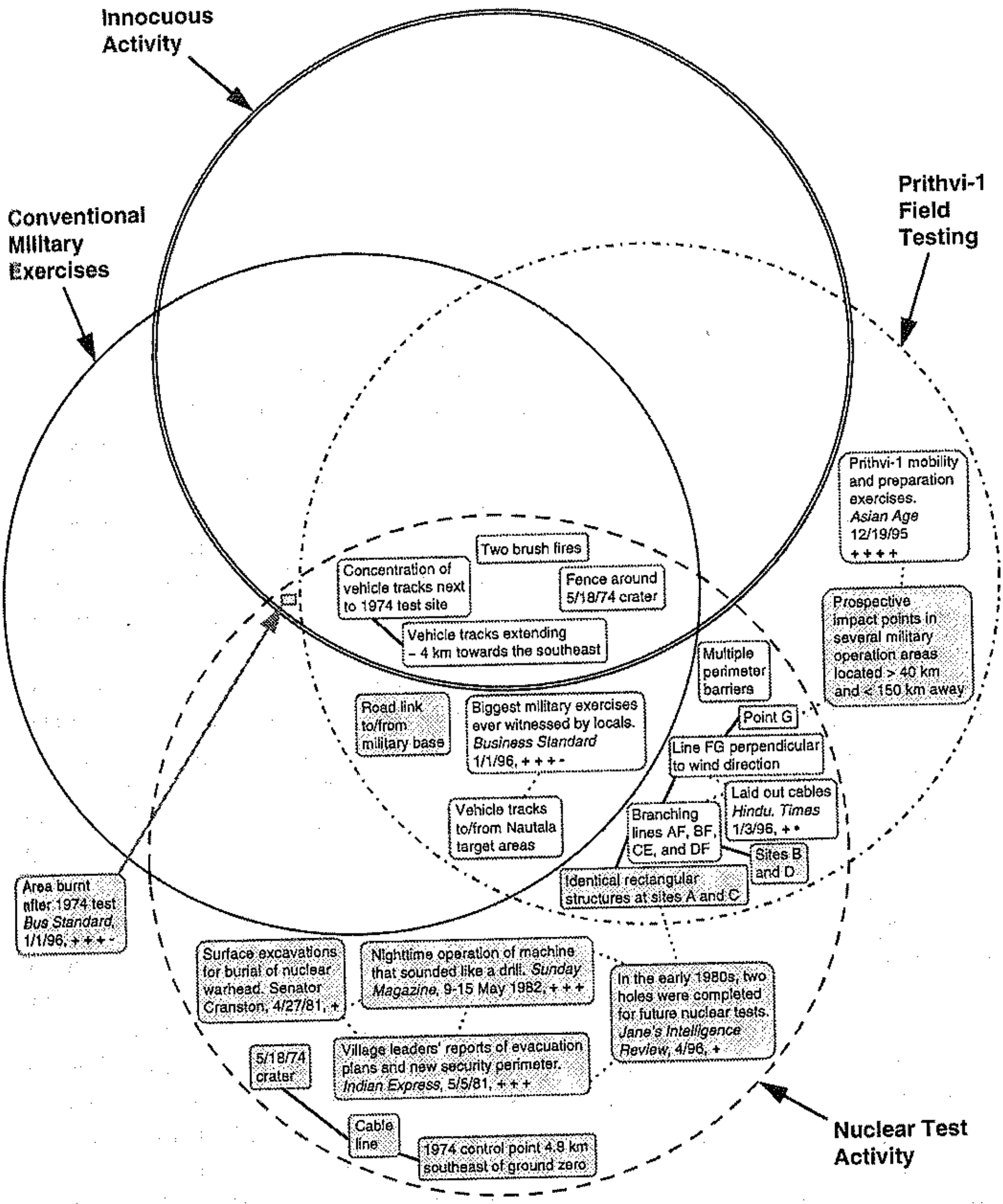

Figure 3: Venn diagram of the Khetolai military range. The circles represent the four separate explanations for the observed activity. Each item of credible evidence was placed onto the diagram in accordance with the table of suppositions (see Appendices C and D). Spatially linked items of evidence were connected together with a solid line, and evidence that could be spatially related were connected with dashed lines. Evidence that predated the 1995 allegations was shaded in order to make it distinct from the new evidence.

drawn to address specifically the 1995 allegations against India, evidence that predated the allegations was shaded in order to make it distinct from the new evidence.

The analysis of the Venn diagram led to three main conclusions. First, the diagram shows that the Khetolai military range has a history of nuclear test activity. It was used for the May 18, 1974 nuclear test, and there is credible evidence from four different sources that indicates shafts were constructed in the early 1980s for two underground nuclear tests there. As shown in the diagram, this evidence predates the 1995 allegations. Second, the diagram shows that there is believable evidence that supports the claim of planned Prithvi field testing at the Khetolai military range. The December 19, 1995 *Asian Age* article that claimed such activity is believable because it made four other factual claims that were verified with the satellite imagery; it was the only news report that accurately described the conventional test ranges in the area as well as the sudden increase in activity at the Khetolai military range (see figure 3 and Appendix C). Moreover, there are five military operation areas nearby that could be well-suited as impact points for Prithvi field tests (see figure 5 inset). Third, the diagram shows that none of the image-derived evidence could be attributed to just one of the four possible activities; one cluster of the image information fit within all four circles, and another cluster fit in both the Prithvi and nuclear test circles. The latter cluster proved to be the most intriguing because it could be spatially linked to other items of evidence that fit in the nuclear test and Prithvi circles. This indicated that the recent activity was consistent with nuclear test preparations, planned Prithvi field testing, or a combination of both. Figures 4 and 5 show how the activity could be interpreted in this way.

In figure 4, the linear traces can be interpreted as the cable lines mentioned in the January 3, 1996 *Hindustan Times* article, oriented perpendicular to the prevailing winds. Such a cable layout would resemble the 1974 cable configuration, which was oriented similarly to keep any accidental release of radioactive debris away from the control point. If India followed the precedent it established in 1974, point G would be the control point situated southeast of the explosion sites (see figure 4). It would then logically follow that the shafts were located at the other end of the linear traces. At the end of the four branching traces, sites A and C—located one kilometer apart from each other—fit the profile of two shaft locations (see figure 4); both are surrounded by multiple layers of perimeter barriers, and both have identical rectangular structures where the same side intersects the inferred cable lines at the exact center of the fenced perimeter (see figure 4). This configuration closely resembles the layout that was used for vertical shaft tests at the US Nevada Test Site.[73]

Site B is equidistant from both of the inferred shaft locations. It is located 500 meters from both sites, which makes it suitable for serving as a diagnostics station for two nuclear tests. Such a station would receive and record the nuclear test data from the ground zero via cable just before the explosion destroyed the hardwired connection. From such a close vantage point, the time response degradation in the cable would be mitigated by the shortened cable length, thereby accommodating the fast rise time requirements for measuring nuclear phenomena from near instantaneous, explosive events. Diagnostic and recording instruments are typically placed close to the explosion point for this reason.[74] The control point could monitor the equipment at site B via a separate cable link along line BG (see figure 4). Site D is located near the entrance to the central area. It can be interpreted as a support base for nuclear test preparations with an unpaved road link to the inferred control point.

In figure 5, point G can be inferred as a missile launch site. Although it lacks wide radius turn loops and it has not been cleared of vegetation, the site is located at the end of a linear trace in a remote area.[75] The linear traces can be interpreted as unpaved road links that connect the launch point with Prithvi and fuel storage sites. The identical rectangular structures at sites A and C can be interpreted as the facilities for temporarily storing the Prithvi missiles, the transporter-erector-launchers (TELs), and volatile fuel (see figure 5). These buildings could be used for such a function given that both are heavily secured, isolated, and connected to the inferred launch point. The road link is approximately three kilometers long so test launches could be done at a safe distance from the basing areas, while still within reach of fire fighting units which could be situated at the support base (site D). It is oriented perpendicular to the prevailing winds, which would keep the toxic exhaust plumes away from the basing area. Site B is equidistant from the two inferred Prithvi facilities, and it is connected to the inferred launch point (see figure 5). It can be interpreted as the missile control point which could be used to coordinate the deployment of Prithvi TELs to the launch point, track the missile after launch, and communicate with the impact site. The cabling described in the January 3, 1996 *Hindustan Times* article could be ignition cables for firing the Prithvi at targets located within five different military operation areas (see figure 5 inset).[76] With respect to the inferred launch point, these operation areas could accommodate the Prithvi-1 minimum range trajectory of 40 km as well as its maximum range trajectory of 150 km.[77]

Furthermore, the field tests could be performed within the Prithvi theater of operations under realistic battlefield conditions while mitigating the chances of unduly alarming Pakistan. As shown in the figure 5 inset, the tra-

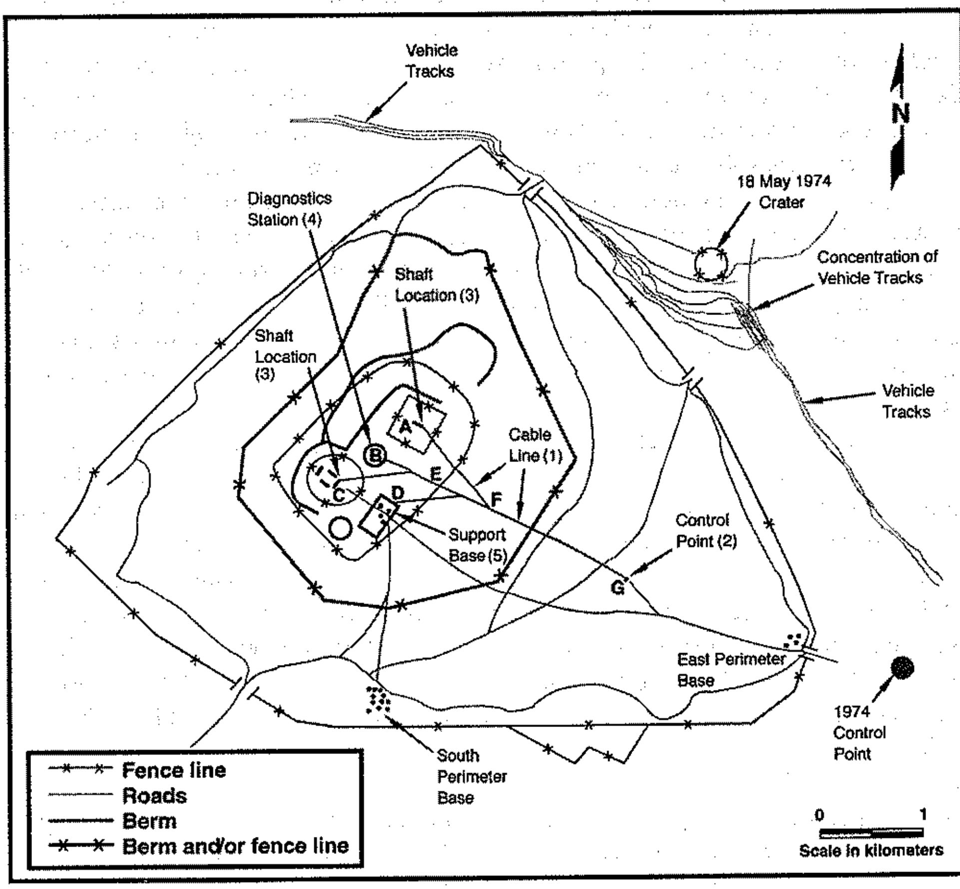

Figure 4: Line map of the Khetolai military range. The figure shows how the various features can be interpreted as nuclear test preparations. The letters correspond with the features labeled in plate 18. The numbers denote the sequence of the deductions that were made to identify the spatially connected features.

jectories from the inferred launch point to the military operation areas would not put the missile on a flight path towards the border with Pakistan. The trajectories would either run parallel with the border or away from the border deeper into Indian territory. Although the Prithvi-1 could reach a small portion of Pakistani territory from the inferred launch point, it would be out of reach of all major civilian or military targets.[78]

Since there are items of evidence that point to nuclear test preparations as well as planned Prithvi field testing, it is within the realm of possibility that the Khetolai military range serves a dual purpose. That is, in the absence of an active nuclear testing program, the facilities and infrastructure at the

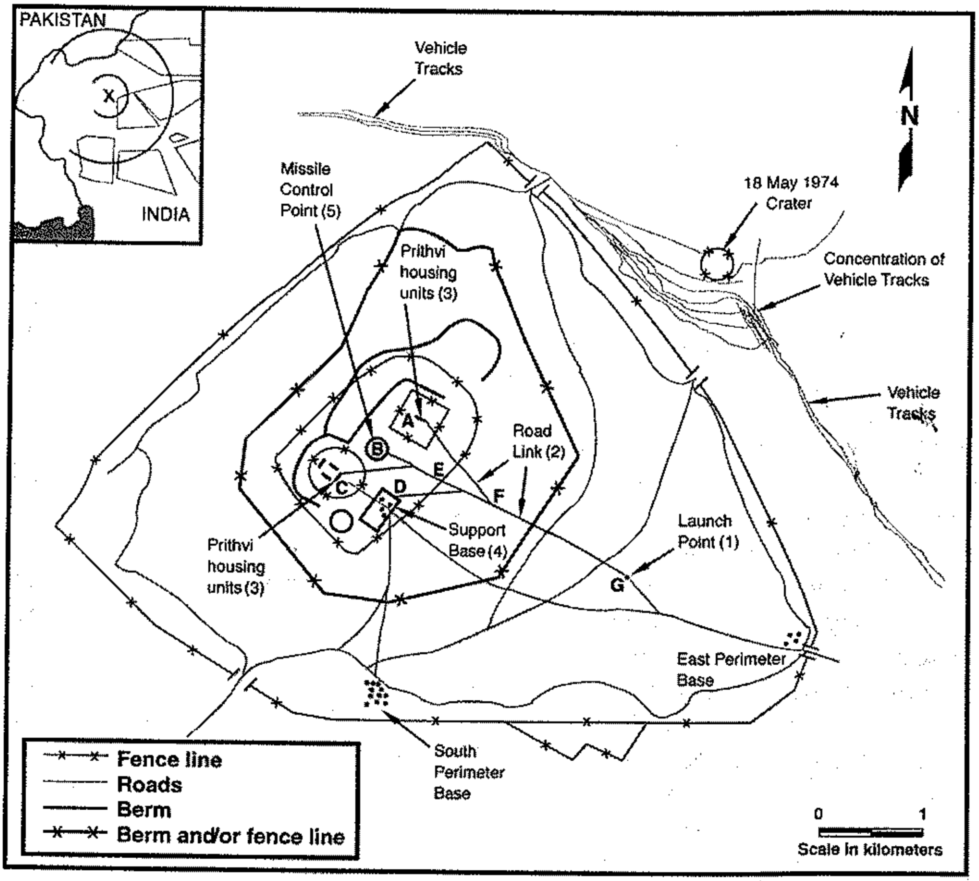

Figure 5: Line map of the Khetolai military range. The figure shows how the various features can be interpreted as planned Prithvi missile testing. The letters correspond with the features labeled in plate 18. The numbers denote the sequence of the deductions that were made to identify the spatially connected features.

The inset is a map of the Indo-Pakistan border in the Rajasthan Desert. The Khetolai military range is located at the X and the polygons are nearby military operation areas. The perimeter of the military operation areas were derived from the March 1991 1:500,000 scale Tactical Pilotage Chart (TPC) H-8C produced by the US Defense Mapping Agency Aerospace Center.

range could be used to conduct a variety of Prithvi exercises for training missile crews. Such activity in the missile's planned theater of operation would be a logical follow-on to the completed series of Prithvi-1 missile development tests along the eastern Indian coastline.[79] If the need for nuclear testing arose later in the future, the facilities and infrastructure at the range could revert back to its original function as a nuclear test site. By assigning a dual role for the Khetolai military range in this way, the personnel, equipment, and infrastructure could be utilized in a routine manner while maintaining India's reserved nuclear testing capability.

CONCLUSIONS AND IMPLICATIONS

Our investigation of the nuclear test allegations against India produced a series of small findings that cumulated into a significant overall result. The first discovery was the exact location of the May 18, 1974 nuclear test. This finding made it possible to search for evidence of the reported 1981, 1982, and 1995 nuclear test activity that allegedly took place in the immediate vicinity of the 1974 test location. The search revealed a handful of military sites, including a military range with a secured area surrounded by open desert near Khetolai village. This range—the Khetolai military range—was used for the May 18, 1974 nuclear test and has been the geographic focal point of the subsequent allegations of nuclear test preparations (see plates 7 and 13). Change detection analysis revealed evidence of large-scale, unusual activity at the Khetolai military range. From being relatively unchanged between May 1992 and March 1995, the Khetolai military range transformed into an active site over a one year period; between March 1995 and March 1996, new security perimeters were built, all terrain vehicle traffic noticeably increased, and several, long linear traces were created.

After these new features were found, the conflicting news reports on the activity (or inactivity) in the Pokharan area were checked to determine which factual claims were consistent with the image-derived information. Articles with verified factual claims were deemed as credible, and articles that were inconsistent with the image information were excluded from the analysis (see Appendix C). The credible articles were used along with the image-derived information to determine whether the recent activity at the Khetolai military range was conventional, missile, nuclear, or innocuous. The characteristic signatures of these different activities were identified and compared with each item of evidence in a table of suppositions and a Venn diagram (see Appendix D and figure 3).

The analysis of the Venn diagram led to three main conclusions. First, the Khetolai military range has a history of nuclear test activity. It was used for the May 18, 1974 nuclear test, and there is credible evidence from four different sources that indicates shafts were constructed in the early 1980s for two additional nuclear tests there. Second, there is believable evidence that supports the claim of planned Prithvi field testing at the Khetolai military range. An Indian news report with four verified factual claims described the planned missile activity, and 1:500,000 scale US DMA maps of the area show five nearby military operation areas that could be well-suited as missile impact points (see figure 5 inset).[80] Third, a significant fraction of the image-derived evidence was consistent with nuclear test preparations, planned Prithvi missile testing, or a combination of both. This evidence could be spatially linked to other items of evidence that were attributable to either nuclear test preparations or planned Prithvi field testing (see figure 3).

Viewing the collected body of evidence as a whole, it is clear that the Khetolai military range is configured for unconventional purposes. It contains all of the large-scale components for nuclear testing (see figure 4), and several of the large-scale components for field missile testing (see figure 5). Thus, nuclear test preparations and planned Prithvi field testing are each plausible, non-exclusive explanations for the recent activity at the Khetolai military range (see figure 3).

Implications for CTB Verification and Compliance

Besides providing new information on India, our investigation of the nuclear test allegations reveals several lessons that are relevant to future CTB verification and compliance. These lessons apply to two types of organizations: those that are observing others with commercial imaging satellites and those that are observed by others with this technology.

The case study illustrates the need to effectively discriminate nuclear test preparations from other military activities. Just as seismologists need to be adept at discriminating between nuclear explosions and routine mining blasts, image analysts need to be able to discriminate ordinary military exercises from maneuvers used as a cover for nuclear test activity. The ability to tell the difference is particularly important for countries where the military may have an integral role in the state's nuclear test programs.

In our analysis of India, the discrimination problem was an acute one. It was complicated not only by the possibility of more than one type of unconventional test activity in the same area, but also by the technical limitations of the available commercial satellite imagery. There were two principal limiting factors: timing and spatial resolution. Because no commercial images were acquired just before or shortly after the nuclear test allegations were made, it was not possible to determine exactly when certain changes occurred. As a result, no insight could be gained by sequentially observing the numerous changes that did take place. In addition, because all of the old and new images were acquired at moderate spatial resolutions, it was not possible to search for small-scale features. If higher resolution imagery were available, the search for specific objects such as drilling equipment, debris piles, instrumentation trailers, TELs, and missile tracking stations could have yielded more information for the Venn diagram analysis. Moreover, the number, size, and movement of vehicles might have provided useful clues about the level and type of activity that was taking place.

The temporal and spatial limitations of the current commercial imaging satellites illustrate the need for more responsive, higher resolution imaging systems. Fortunately, better satellites are presently under construction and are scheduled for deployment over the next 6 to 18 months. These satellites will acquire panchromatic images at a 1–3 meter ground sample distance and multispectral images at a 4 meter ground sample distance.[81] The companies that will sell these images plan to deliver the digital products within 72 hours of acquisition. If these satellites perform as specified, the CTB verification regime will be enhanced significantly.

Even if the planned technical improvements take place, the high demand for collateral information will remain. As demonstrated in this study, media reports and scientific papers were valuable, sometimes critical, sources of information for the imagery analysis. The villagers' eyewitness accounts and the Indian government's official and unofficial statements were particularly important for determining where to search for the alleged activities.

In countries with a controlled press and restricted academia, it may be more difficult to collect collateral information that is high quality and in sufficient quantity to be useful. Under such adverse circumstances, alternative information sources would have to be utilized, including reports from dissidents, emigrants, the foreign media, human rights organizations, and humanitarian agencies.[82]

As commercial high-resolution satellite imaging becomes more commonplace, nuclear-capable states—particularly the nuclear weapons states—will likely be subjected to an unprecedented amount of overhead observation by numerous governments, non-governmental organizations, and international agencies. With this increased transparency, imaged states will be compelled to avoid non-nuclear activities that could easily be misconstrued as nuclear test preparations—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 CTB provisions, state-parties will have the *de facto* obligation to conduct their sensitive, non-nuclear activities in observably, unambiguous ways.

Utility of Commercial Satellite Imagery for CTB Verification

The investigation of the recent Indian nuclear test allegations was done specifically to test the utility of current commercial imaging satellites for CTB verification. In contrast with the previous remote sensing studies of known nuclear test sites, this investigation demonstrated in a realistic CTB scenario how the latest commercial imaging satellites could provide invaluable information for test ban verification *before* the occurrence of a nuclear test.

The CTB verification exercise empirically showed how commercial satellite imagery filled a critical technical niche in the overall verification regime. With journalists acting as *de facto* on-site and off-site inspectors for the hypothetical CTB, the satellite imagery was effectively used to check the conflicting factual claims that were made by the media as well as reveal new facts that were not in the news reports. When combined with the credible articles, the image-derived information presented a clearer picture on the nature and extent of the observed activity. Although it did not provide conclusive proof that led to a single unequivocal explanation, the image information did make it possible to conduct a technical analysis and make an informed assessment based on the collected body of evidence.

The investigation provided a glimpse of commercial satellite imagery's future role as an instrument for CTB verification. As the only "pre-test" monitoring technology that will be openly available on the commercial market, it is likely to be used extensively by numerous states to verify compliance with the treaty. States could use the imagery to make a case to the CTBT Organization for an on-site inspection. In addition, the imagery could be used to trigger intensified monitoring of a suspect site with "post-test" technologies—particularly seismic and radionuclide sensors.[83]

The decentralized application of this open source technology will add a new layer of capability to the CTB verification regime. And with the continued improvements in spatial and temporal resolution, commercial imaging satellites will most likely be used to accomplish verification tasks that will be far more sophisticated than the ones that were done for this study. The question for the future is no longer whether commercial satellite imagery will be applied to verify a CTB, but rather what lasting impact will it have on the implementation of the treaty.

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APPENDIX A: CALCULATING THE DIRECTION OF THE SHADOWS IN THE HELICOPTER PHOTO OF THE MAY 18,1974 SUBSIDENCE CRATER

The January 1975 IAEA proceedings on peaceful nuclear explosions contain a technical paper by R. Chidambaram and R. Ramanna that describes India's 1974 nuclear test. The paper includes a photograph of the subsidence crater that formed shortly after the nuclear explosion (see plates 1 and 4). The caption under the picture states that the photo was "taken from a helicopter on 18 May 1974, soon after the experiment."[84] Near the end of the paper, the authors state that the helicopter observation of the crater was made "an hour after the experiment had taken place."[85] Thus, the aerial photo must have been taken at this time.

Using the published information on the helicopter photo as well as the seismic data from the Indian nuclear test, the direction of the photographed shadows was calculated. The shadow orientation was needed in order to establish the bearing of the helicopter-borne camera at the time the picture was taken. This information was then used to render the May 24, 1992 KVR-1000 satellite image as a perspective view that replicated the aerial camera geometry (see plates 4 and 5).

At 0 hrs ephemeris time on the day of the Indian nuclear test, the sun was located at the following equatorial coordinates:[86]

$$\delta = 19.42° \qquad \text{(A-1)}$$

$$\alpha = 54.38° \qquad \text{(A-2)}$$

where

δ — apparent declination (i.e., the sun's latitude)
α— apparent right ascension (i.e., the sun's longitude)

The apparent declination is measured with respect to the Earth's equatorial plane. The apparent right ascension is measured with respect to the first point of Aries—a vector oriented along the intersection of the Earth's equatorial plane and the Earth's orbital plane pointing at the sun on the vernal equinox.

According to the seismic data reported by the International Seismological Center, the nuclear explosion took place at 26.99 $\pm$ .028° N, 71.80 $\pm$ .033° E. The time of detonation was 02:34:55.40 $\pm$ .17 GMT on May 18, 1974. The helicopter observation was made one hour after the nuclear test so the aerial

Table A.1: Value of input parameters for equations A-3 and A-4 that pertain to the acquisition time of the helicopter photo and the location of the subsidence crater. The values were derived from the Chidambaram and Ramanna paper, the May 1974 *ISC Seismological Bulletin*, and the 1974 *Ephemeris Almanac*.

t_{GMT}	D	t_o	λ
3.58 hrs	138 calendar days	6.62 hrs	71.80°

photo must have been taken at approximately 03:35 hrs GMT. To relate this time with the sun's position in the sky, the photo acquisition time was converted to local sidereal time (LST), which is the time at a specific point on the Earth measured with respect to the periodic motion of the distant stars in the sky. Time in GMT can be converted to LST in two steps:[87]

$$t_{GST} = (1.002743)\, t_{GMT} + (.065709)\, D + t_0 - 24 \qquad \text{(A-3)}$$

$$t_{LST} = \begin{cases} t_{GST} + \dfrac{\lambda}{15} + 24 & \text{if } t_{GST} < 0 \\ t_{GST} + \dfrac{\lambda}{15} & \text{if } t_{GST} \geq 0 \end{cases} \qquad \text{(A-4)}$$

where

t_{LST} — local sidereal time (in decimal hours)
t_{GST} — Greenwich sidereal time (in decimal hours)
t_{GMT} — Greenwich mean time (in decimal hours)
D — number of days since midnight on 31 December of the preceding year (in calendar days)
t_0 — apparent sidereal time at 0 hrs GMT on 31 December of the preceding year (in decimal hours)
λ — longitude of the point of interest (in degrees)

Table A.1 lists the value of each input parameter for equations A-3 and A-4 that was needed to convert the acquisition time of the helicopter photo to decimal hours LST.

$$t_{LST} = 24.07 \text{ hrs} \qquad \text{(A-5)}$$

To relate this LST value at the estimated 1974 test location with the sun's position, the hour-angle, H, was calculated. H is the angular distance at a specific point on the Earth from the local meridian to an object's apparent right ascension.[88] It can be calculated by using the following equation:

$$H = (15)\ t_{LST} - \alpha \qquad \text{(A-6)}$$

where

H—hour-angle (in degrees)
t_{LST}—local sidereal time (in decimal hours)
α — apparent right ascension (in degrees)

Using the numbers from equations A-2 and A-5,[89]

$$H = 306.63° \qquad \text{(A-7)}$$

Equation A-7 represents the hour-angle between the seismically estimated meridian of the photographed crater and the sun's longitude at the time the picture was taken. Using this hour-angle value, the sun's elevation and azimuth were calculated:[90]

$$E = \sin^{-1}[\sin\delta \sin\phi + \cos\delta \cos\phi \cos H] \qquad \text{(A-8)}$$

$$A = \begin{cases} \cos^{-1}\left(\dfrac{\sin\delta - \sin\phi \sin E}{\cos\phi \cos E}\right) & \text{if } \sin H < 0 \\ 360 - \cos^{-1}\left(\dfrac{\sin\delta - \sin\phi \sin E}{\cos\phi \cos E}\right) & \text{if } \sin H \geq 0 \end{cases} \qquad \text{(A-9)}$$

where

A—azimuth measured clockwise from north (in degrees)
E—elevation (in degrees)
δ — apparent declination (in degrees)
ϕ — latitude of the point of interest (in degrees)
H—hour-angle (in degrees)

Table A.2 lists the value of each input parameter for equations A-8 and A-9 that was needed to calculate the sun's elevation and azimuth at the instant the helicopter photo of the subsidence crater was acquired.

$$E = 40.56° \qquad \text{(A-10)}$$

$$A = 86.83° \qquad \text{(A-11)}$$

Measured clockwise from north, the azimuth angle of 86.83° indicates that the sun was positioned approximately due east of the subsidence crater when the aerial picture was taken, and the bush shadows shown in the foreground

Table A.2: Value of input parameters for equations A-8 and A-9 that pertain to the acquisition time of the helicopter photo and the location of the subsidence crater. The values were derived from the Chidambaram and Ramanna paper, the May 1974 *ISC Seismological Bulletin*, and the 1974 *Ephemeris Almanac*.

δ	ϕ	H
19.42°	26.99°	306.46°

of the photo cast westward towards the camera (see plates 1 and 4). Thus, the helicopter-borne camera must have been positioned west of the 1974 test location and pointed east to acquire the picture of the crater shortly after the nuclear explosion.

APPENDIX B: LOCATING THE CONTROL POINT FOR THE MAY 18, 1974 NUCLEAR TEST

The control point for the May 18, 1974 nuclear test was located after a reexamination of the 1975 technical paper by Chidambaram and Ramanna.[91] This paper was revisited because of the new vehicle tracks around the 1974 test location that were observed in the 1996 SPOT satellite images. The two historical pictures in the paper were analyzed for topographic clues that could help explain why there was renewed activity around the old nuclear test site. The camera position and orientation for the ground photo and helicopter photo were determined and then compared with the ground shown in the 1996 SPOT images. The comparison did not yield a conclusive explanation for the new activity. However, the combination of the oriented ground photo with the ancillary descriptions in the text did reveal the location of the 1974 control point.

Plate B.1 shows the ground photo which was acquired as the underground explosion displaced the surface upward. The caption describes the picture as a "[p]hotograph of the mound near its peak position as taken from the control point."[92] In the picture, the cable line and adjacent road can be seen leading to the explosion site in the distance. The picture also shows a desert tree in the foreground as well as tire tracks that veer off the main dirt road leading to the camera's location at the control point.

The presence of the cable line and camera suggests that the control point was used for firing the nuclear device and observing the explosion. The control point was also used for monitoring radioactive fallout; one of two health physics laboratories was stationed there.[93] In addition, deposition trays and health physics survey teams were dispersed throughout the area. Figure B.1 shows a diagram from the Chidambaram and Ramanna paper that maps the location of the deposition trays and health physics survey teams relative to the 1974 explosion site.

The paper does not provide the exact location of the control point. However, if one presumes that the health physics laboratory at the control point contained deposition trays or was occupied by a health physics survey team, the control point can reasonably be inferred to be one of the nine radioactive monitoring stations mapped in figure B.1. The nine candidate control points can be whittled down to one through a photogrammetric process of elimination. Each prospective control point can be compared with the camera and shadow orientation shown in the ground photo that was taken at the actual control point (see plate B.1). If one of the radioactive monitoring stations is indeed the control point, it would have to fit the optical geometry of the ground photo.[94]

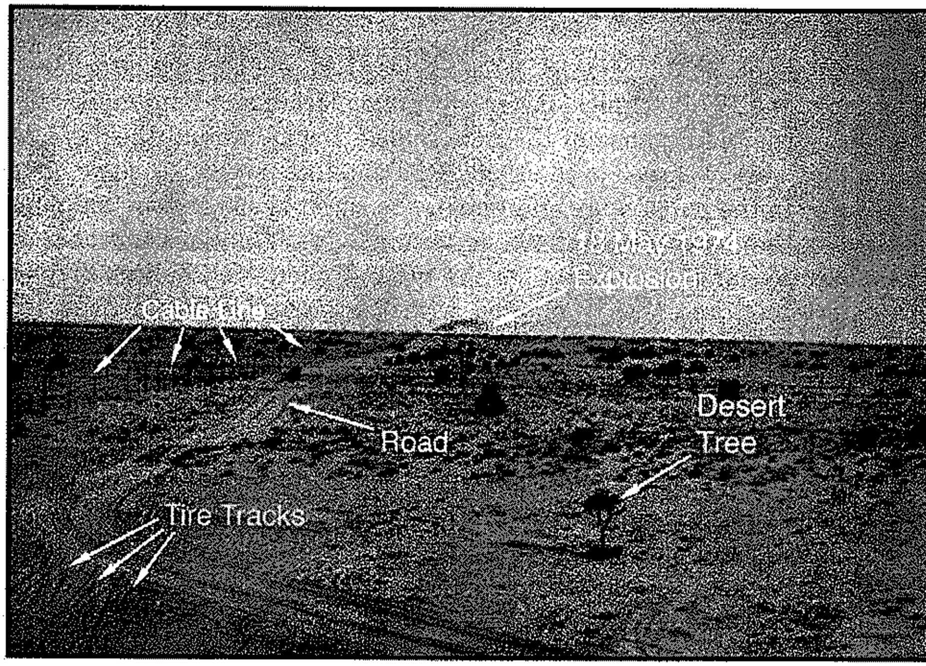

Plate B.1: Photo of the 1974 underground nuclear explosion displacing the surface upward. The picture was taken at the control point. It shows the mound in the distance as well as the cable line and road leading to the explosion site. It also shows a desert tree in the foreground and tire tracks that lead to the control point. (Source: Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 430)

The ground photo has two photogrammetric characteristics that define its orientation: the line-of-sight to the explosion and the direction of the shadows. The former is given in figure B.1 for each of the nine prospective control points. The latter can be seen at a desert tree in the foreground of the picture (see plate B.1), and calculated from the photo acquisition time and geographic coordinates of the 1974 explosion site. The photo acquisition time corresponds with the approximate time of detonation, since the picture shows the near instantaneous surface rise from the explosion: 02:34:55.40 ± .17 GMT on May 18, 1974.[95] The geographic coordinates of the 1974 ground zero were obtained from the May 24, 1992 KVR-1000 image and the March 25, 1995 SPOT image: 27.095 ± .001° N, 71.752 ± .001° E (see plate 5). With these input parameters, the direction of the tree shadow was calculated by sequentially applying equations A–3, A–4, A–6, A–8, and A–9 (see Appendix A). Table B.1 lists the value

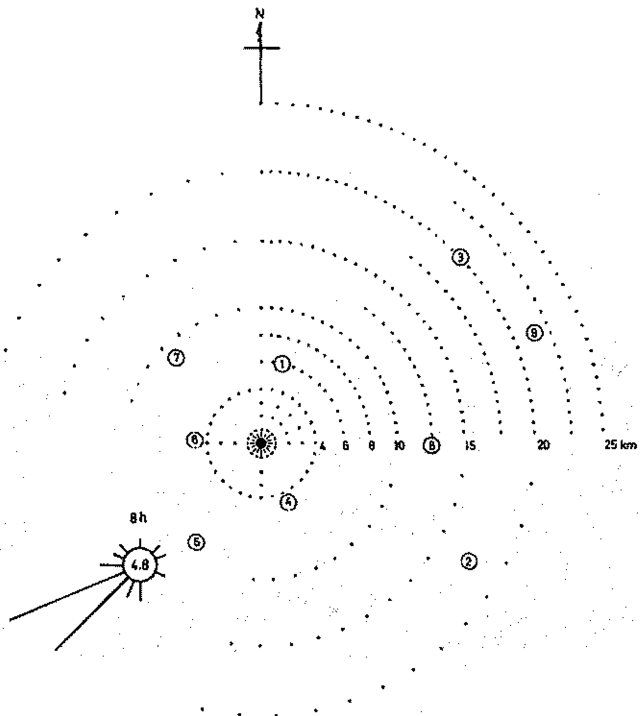

Figure B.1: Location of the deposition trays and health physics survey teams relative to the 1974 explosion site. The wind rose in the lower left corner shows the wind conditions shortly before the nuclear test was conducted. (Source: Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 426)

of each input parameter for these equations in the appropriate units. The calculation yielded the following values for the sun's elevation and azimuth at the instant the ground photo of the explosion was acquired:

$$E = 27.33° \quad \text{(B-1)}$$

$$A = 81.03° \quad \text{(B-2)}$$

where

A — azimuth (in degrees)
E — elevation (in degrees)

Measured clockwise from north, the azimuth angle of 81.03° indicated that the sun was located east-northeast of the control point when the ground photo was taken, and the tree trunk shadow pointing to the left side of the photo cast towards the west-southwest. Given this directional indicator, the camera

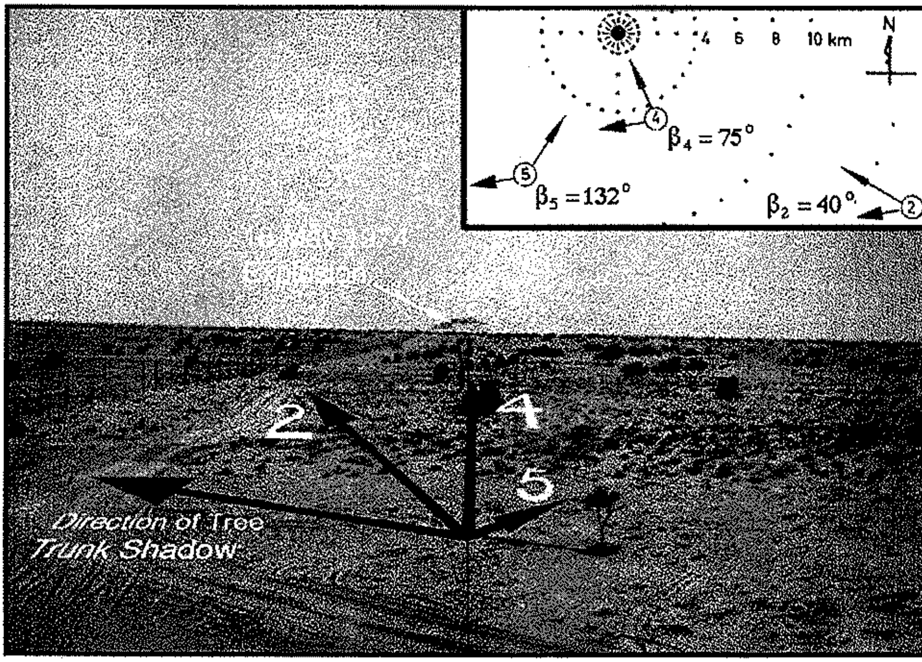

Plate B.2: Ground photo of mound with tree shadow vector and line-of-sight vectors for stations 2, 4, and 5. The inset shows the β values—the clockwise angular distance from the shadow vector to the line-of-sight vector—for stations 2, 4, and 5. Projected onto the ground with respect to the shadow line from the vertical tree trunk, the line-of-sight vector from station 4 was the only one that pointed along the line-of-sight of the camera towards the explosion site. This conclusively established station 4 as the 1974 control point.

at the control point must have been located south of the 1974 test location. This finding eliminated six of the nine candidate control points shown in figure B.1; only stations 2, 4, and 5 were located south of the explosion site. The pool of possible control points was reduced further by calculating β—the clockwise angular distance from the shadow vector to the line-of-sight vector—for the ground photo (see plate B.2 inset). Plate B.2 shows that the calculated β value at station 4 was the only one that matched the actual β value of the ground photo. Thus, station 4 was the control point for the 1974 nuclear test, and it was located approximately 4.8 km southeast of the detonation point at an azimuth angle of 156° (see figure B.1 and plate 16).

Table B.1: Value of input parameters for equations A-3, A-4, A-6, A-8, and A-9 that pertain to the acquisition time of the ground photo (plate B.1) and photogrammetric location of the May 18, 1974 test. The values were derived from the Chidambaram and Ramanna paper, the May 1974 *ISC Seismological Bulletin*, the 1974 *Ephemeris Almanac*, and the satellite image analysis.

Input Parameter	Value
apparent declination (i.e., the sun's latitude), δ	19.42°
apparent right ascension (i.e., the sun's longitude), α	54.38°
photo acquisition time in GMT, t_{GMT}	2.58 hrs
number of days since midnight on Dec 31, 1973, D	138 calendar days
apparent sidereal time at 0 hrs GMT on Dec 31, 1973, t_o	6.62 hrs
latitude at subsidence crater, ϕ	27.095°
longitude at subsidence crater, λ	71.752°
hour-angle, H	291.50°

APPENDIX C: ASSESSING THE CREDIBILITY OF THE NEWS REPORTS ON ALLEGED INDIAN NUCLEAR TEST ACTIVITY

Following the image analysis, the credibility of each news report on alleged Indian nuclear test activity was checked by comparing the factual claims with the image-derived information. If a specific factual claim in a news report was corroborated or consistent with the image-derived information, it was assigned a '+' indicator. If the claim was inconsistent with the imagery, it was assigned a '–' indicator. If a factual statement was checked with overhead imagery and the result was inconclusive, it was given a '•' indicator. Other articles that could be linked to these factual claims were also assigned the corresponding indicators. The total number of the three indicators for each article provided a semi-quantitative way of assessing the believability of other factual claims in the article that could not—for purely technical reasons—be checked with the available commercial satellite imagery.

For example, consider the January 1, 1996 *Business Standard* article by Damandeep Singh. This article made six factual claims:

(i) A new fence was built around the 1974 nuclear test site.
(ii) Cattle routinely grazed around the 1974 test site.
(iii) The 1974 test site was located around four kilometers down a sandy trail off the main road just before one nears Loharki village.
(iv) In 1995, locals "had not seen any earthmoving or civil construction activity."
(v) Locals remember that the "grass and shrubs in the area were burnt" shortly after the 1974 nuclear test.
(vi) In the fall of 1995, locals had seen army exercises that were the "biggest ever witnessed by them."

The first claim was verified in the March 1996 SPOT images, which show a new, light-toned ring around the 1974 subsidence crater, and in the March 6, 1996 Radarsat image which shows a circular arc along the periphery of the crater. The second claim was supported by all of the SPOT images which show differential vegetation growth near the 1974 test site, indicating livestock-grazing outside the fenced area. The third claim was confirmed by the March 25, 1995 SPOT image, which shows the 1974 test site located approximately four kilometers off the main road to Loharki. The fourth claim was refuted by the March 1996 SPOT images which show perimeter reinforcement and extensive ground clearing in the immediate vicinity of the 1974 test site. The fifth and sixth claim could not be verified because the satellite imagery did not date back to 1974, and because the new imagery was too coarse in spatial resolution to show personnel and vehicles. However, both facts were deemed as believable because the article made three obscure factual claims that were independently verified and only one claim that proved to be incorrect.

Table C.1 lists the results from the credibility assessment. For each news article, the table lists the factual claims that could be checked with the satellite imagery and compares each claim with the image-derived information. The verified facts and believable claims were then incorporated into the table of suppositions (see Appendix D) and the Venn diagram (see figure 3).

Table C.1: Credibility Assessment of News Reports Using Image-Derived Information

News Report	Factual Claims	Image-Derived Evidence
Senator Alan Cranston, "Nuclear Arms Race in South Asia Endangers US Security Interests," *Congressional Record*, US Senate, April 27, 1981, pp. 7375-7377.	"The Indian test site involves surface excavations for burial of a nuclear warhead—for an underground test—and has been under preparation for several months in the (T)har Desert at Pokharan. It is alongside the site of India's 1974 bomb test, approximately 100 miles southeast of the Pakistani border."	+ This statement is consistent with the May 5, 1981 *Indian Express* article and the May 9–15, 1982 *Sunday Magazine* article—two reports with factual claims that were verified by the satellite image analysis.
Rahul Bedi, "Pokhran Full of N-Test Talk," *Indian Express*, May 5, 1981, p. 1.	"Around the early 1960s over 20 villages in the Pokhran tehsil were taken over by the army and the area closed to the public."	+ Analysis of the December 12, 1961 KH-3 image and the March 25, 1995 SPOT image revealed that a large tract of land northwest of Pokharan had been taken out of farm production and taken over by the military (see plates 6 and 7). The May 24, 1992 KVR-1000 image shows that Malka village ceased to exist. Analysis of the May 24, 1992 KVR-1000 image, the March 25, 1995 SPOT image, and the March 6, 1996 Radarsat image indicate that Nautala village was abandoned.
	"However, as the area is drought-prone, and sheep-rearing is the mainstay of the villagers, the Bishnois would take livestock to the wells of the acquired villages within the forbidden area with official connivance."	+ The March 25, 1995 SPOT image shows differential vegetation growth at fence lines around military areas, indicating livestock grazing just outside the secured perimeter in abandoned areas such as Malka village and the 1974 subsidence crater (see plate 13).
	"The deputy sarpanch said that barbed wire fencings suddenly went up three months ago around three kilometres south of the old blast site, which is part of the Pokhran firing range for tanks and artillery, enclosing an area roughly eight kms long and three kms wide."	+ South of the 1974 subsidence crater next to the tank firing ranges and conventional target areas, the May 24, 1992 KVR-1000 image and the March 25, 1995 SPOT image show a fenced area (see plates 7 and 13). The area is secured by a triangular-shaped perimeter with a base and height of 5.7 km and 6.1 km respectively.

Table C.1:(Continued) Credibility Assessment of News Reports Using Image-Derived Information

News Report	Factual Claims	Image-Derived Evidence
Shubhabrata Bhattacharya, "Another Nuclear Blast at Pokhran?," *Sunday Magazine*, Calcutta, May 9–15, 1982, pp. 12-15.	"The site was chosen sometime after the 1965 Indo-Pak war and in 1969 two villages, Malka and Kala, were evacuated to make way for the field firing range. Later, four more villages—Naotala, Etah, Taorki, and Sudhia—were also similarly evacuated around 1971."	+ The May 24, 1992 KVR-1000 image shows that Malka village ceased to exist. Analysis of the May 24, 1992 KVR-1000 image, the March 25, 1995 SPOT image, and the March 6, 1996 Radarsat image indicate that Nautala village was abandoned.
	"The 1974 explosion was carried out near the abandoned Malka village which is located about four km away from Loharki, a village on the Ramdeora-Nachna road."	+ The May 24, 1992 KVR-1000 image and the 1955 US AMS map sheet (NG-42-04) confirmed that the May 18, 1974 nuclear test took place at Malka—just 1.5 km southwest of the village center.
	"They (the Loharki villagers) said that for the past one year the army had cordoned off an area between the earlier test site of Malka and Khetolai..."	+ Between the May 18, 1974 crater and Khetolai, the May 24, 1992 KVR-1000 image and the March 25, 1995 SPOT image show a cordoned area (see plates 7 and 13).
"UNI Correspondent Visits Pokhran A-Blast Site," *Patriot*, New Delhi, January 17, 1983, p. 7.	"A UNI correspondent who recently visited the (1974 test) site situated about 20 km from Pokharan town saw no sign of life except stray crows and grazing goats."	+ The March 25, 1995 SPOT image shows differential vegetation growth at fence lines around military areas, indicating livestock grazing just outside the secured perimeter in abandoned areas such as Malka village and the 1974 subsidence crater (see plate 13). + The May 24, 1992 KVR-1000 image and the March 25, 1995 SPOT image indicate that the 1974 test site is about 20 km from Pokharan town. To be exact, it is 24.8 km away.

Table C.1:(Continued) Credibility Assessment of News Reports Using Image-Derived Information

News Report	Factual Claims	Image-Derived Evidence
	"The underground explosion which catapulted India to nuclear might made a huge crater about 60 feet in diameter."	– Analysis of the May 24, 1992 KVR-1000 image of the 1974 subsidence crater revealed a crater diameter of approximately 165 meters—not 60 feet.
Tim Weiner, "India Suspected of Preparing for A-Bomb Test," *New York Times*, December 15, 1995, p. A6.	US spy satellites had "recorded scientific and technical activity at the Pokharan test site in the Rajasthan Desert."	• The described activity was too vague in detail and location to verify with the commercial satellite imagery.
R. Jeffrey Smith, "Possible Nuclear Arms Test by India Concerns US," *Washington Post*, December 16, 1995, p. A17.	"The (Pokharan) site has been routinely maintained by India for the past two decades, but US intelligence officials recently noted efforts to clean out a deep underground shaft for lowering a nuclear weapon into the earth."	• The spatial and temporal resolution of the 1996 SPOT and Radarsat imagery was too coarse to determine whether the described activity took place. In addition, the described location of the alleged activity was too vague to verify with the commercial satellite imagery.
	"They also noted 'possible preparation for instrumentation' of a blast to determine whether it occurred as predicted, the official said."	• The spatial and temporal resolution of the 1996 SPOT and Radarsat imagery was too coarse to determine whether the described "possible" activity took place. In addition, the described location of the alleged activity was too vague to verify with the commercial satellite imagery.

Table C.1:(Continued) Credibility Assessment of News Reports Using Image-Derived Information

News Report	Factual Claims	Image-Derived Evidence
M.D. Nalapat, "Defense Officials Upset over Report on N-test," *The Times of India*, Bombay, December 18, 1995, p. 1.	"Senior (Indian) defense officials claim that the Clinton Administration had made available satellite data to selected US correspondents without informing them that Pokhran has four ranges: A, B, C, and D. And of the four, only range A is meant for nuclear experiments 'and here there has been no activity.'" According to these officials, the activity mentioned by the spy satellites was taking place in range B and C, 'which are used by the army.' These ranges, along with range D (used by the air force) 'have been the site of exercises for many years, and there is nothing unusual in this.'"	+The March 25, 1995 SPOT image shows tank firing ranges northwest of Pokharan (see plate 10). The May 24, 1992 KVR-1000 image shows two conventional target areas just north of the tank firing ranges (see plate 11). The numerous craters in the target areas could have been the result of artillery firing, aerial bombardment, or both. – The March 2, 1996 and March 18, 1996 SPOT images show large-scale, unusual activity in the immediate vicinity of the 1974 nuclear explosion site (see plates 16 and 18). So, either the article's claim of no activity at the site for nuclear experiments is incorrect, or the article is referring to another site near Pokharan that is reserved for nuclear experiments.
"Using a Pretext of the Nuclear Test," *Jansatta*, Delhi, December 19, 1995, p. 6.	"The areas that the US satellite has been photographing in Pokaran is the arena where Indian forces go to conduct their practice exercises. The actual site reserved for the nuclear explosions does not appear in the photographs at all as it is devoid of any activity."	+ The March 25, 1995 SPOT image shows tank firing ranges northwest of Pokharan (see plate 10). The May 24, 1992 KVR-1000 image shows two conventional target areas just north of the tank firing ranges (see plate 11). The numerous craters in the target areas could have been the result of artillery firing, aerial bombardment, or both. – The March 2, 1996 and March 18, 1996 SPOT images show large-scale, unusual activity in the immediate vicinity of the 1974 nuclear explosion site (see plates 16 and 18). So, either the article's claim of no activity at the site for nuclear experiments is incorrect, or the article is referring to another site near Pokharan that is reserved for nuclear experiments.

Table C.1:(Continued) Credibility Assessment of News Reports Using Image-Derived Information

News Report	Factual Claims	Image-Derived Evidence
Pravin Sawhney, "Preparations at Pokharan Site Reportedly for Missile Test," *The Asian Age*, Delhi, December 19, 1995, pp. 1, 4.	"The Pokharan range is divided into four parts: range A for artillery firing which needs a maximum open area of 40 km, range B is traditionally for armour exercises, range C is for the Indian air force and range D, where the 1974 peaceful nuclear implosion was conducted, is cordoned off as restricted area." The only normal activity at range D is the movement of a few security guards and an engineer platoon of the army. Scientists are known to move in and out of this area, but the overall activity is minimal. Now with India planning to test Prithvi there, the activity at D range has picked up."	+ The March 25, 1995 SPOT image shows tank firing ranges northwest of Pokharan (see plate 10). + The May 24, 1992 KVR-1000 image shows two conventional target areas just north of the tank firing ranges (see plate 11). The numerous craters in the target areas could have been the result of artillery firing, aerial bombardment, or both. + The May 24, 1992 KVR-1000 image and the March 25, 1995 SPOT image show a cordoned area adjacent to the 1974 explosion site. The March 2, 1996 SPOT image, the March 18, 1996 SPOT image, and the March 6, 1996 Radarsat image show a new fence around the 1974 subsidence crater. + Analysis of the May 24, 1992 KVR-1000 image and the March 25, 1995 SPOT image indicated that no large-scale changes took place in the vicinity of the 1974 test site over the three year period. The March 2, 1996 and March 18, 1996 SPOT images show extensive activity in this area since March 1995.

Table C.1:(Continued) Credibility Assessment of News Reports Using Image-Derived Information

News Report	Factual Claims	Image-Derived Evidence
Prem Shankar Jha, "Maintaining India's Nuclear Option," *The Hindu, Madras*, December 30, 1995, p. 12.	"An Indian correspondent who visited Pokaran and talked to the villagers in adjoining villages has reported that a new barbed wire fence now rings off the vast site of the 1974 test, that there is evidence of earth moving equipment having been used and that villagers claim that an entire new hill has been created from the excavated sand and mud. However, he also reports that electrical wiring conduits that the Americans claim to have seen, may have been a water pipe laid to one of the villages."	+ The March 2, 1996 SPOT image, the March 18, 1996 SPOT image, and the March 6, 1996 Radarsat image show a new fence around the 1974 subsidence crater. + Analysis of the March 2, 1996 and March 18, 1996 SPOT images revealed that earthmoving equipment was used to build new security perimeters as well as several new linear traces. • No evidence of a new hill of excavated sand and mud was found in any of the images. • No evidence of a water pipe leading to one of the nearby villages was found in any of the images.
Damandeep Singh, "Heavy Military Build-Up Near First Nuclear Explosion Site," *Business Standard*, Dehli, January 1, 1996, pp. 1, 3.	"Villagers in nearby Loharki, however, point to two odd happenings—army build-up in the region in recent weeks on a scale not seen before and a new, sturdy fence that has come up, around the old (test) site."	+ The March 2, 1996 SPOT image, the March 18, SPOT image, and the March 6, 1996 Radarsat image show a new fence around the 1974 subsidence crater.
	"Loharki's residents also find it hard to explain the emergence of the fence. A sandy trail, marked with fresh tyre tracks, leads off just before one nears the village, with the (1974) site located around four km down the trail."	+ Analysis of the SPOT images revealed that the article accurately described the location of the 1974 test site from the main road that links with Loharki village.

Table C.1:(Continued) Credibility Assessment of News Reports Using Image-Derived Information

News Report	Factual Claims	Image-Derived Evidence
	"Pancha Ram, a Loharki farmer, finds this surprising as villagers have been using the area in and around the site for grazing their cattle."	+ The March 25, 1995 SPOT images shows differential vegetation growth at fence lines around military areas, indicating livestock grazing just outside the secured perimeter in abandoned areas such as Malka village and the 1974 subsidence crater (see plate 13).
	"They (the villagers) had not seen any large-scale earthmoving or civil construction activity."	– Analysis of the March 2, 1996 and March 18, 1996 SPOT images revealed that large-scale earthmoving and civil construction did take place approximately 8.5 kilometers south-southwest of Loharki village. The activity involved the construction of new security perimeters and linear traces.
P.R. Chari, "Reports of Test Forcing Nuclear Decision," *The Hindustan Times*, Delhi, January 3, 1996, p. 11.	"These activities comprised fencing off the old test site, piling up earth to construct a huge sand dune, laying down cables, and so on."	+ The March 2, 1996 SPOT image, the March 18, 1996 SPOT image, and the March 6, 1996 Radarsat image show a new fence around the 1974 subsidence crater. • No evidence of a new huge sand dune was found in any of the images.
W.P.S. Sidhu, "India's Nuclear Tests: Technical and Military Imperatives," *Jane's Intelligence Review* **8** (4), April 1996, pp. 170-173.	"Besides, senior nuclear scientists have revealed that open-source reports about India's preparations for nuclear tests in the early 1980s were accurate."	+ This statement is consistent with the May 5, 1981 *Indian Express* article and the May 9–15, 1982 *Sunday Magazine* article—two reports that contain factual claims that were verified by the satellite image analysis.

APPENDIX D: COMPILING A TABLE OF SUPPOSITIONS FROM THE COLLECTED EVIDENCE ON THE KHETOLAI MILITARY RANGE

The collected evidence conclusively proved that large-scale, unusual activity did take place at the Khetolai military range. With that fact established, each item of evidence was examined to determine whether the observed activity was conventional exercises, nuclear test preparations, Prithvi field testing, or something completely different. The analysis was done by tabulating a list of suppositions—a series of propositions that explained how each item of evidence could be attributed to at least one of the four activities. Table D.1 lists the collected evidence and the various explanations for it. To determine what kind of activity actually took place at the Khetolai military range, each item of evidence was placed onto a Venn diagram based on the enumerated suppositions (see figure 3), and then analyzed for spatial and logical relationships that were characteristic of at least one of the four possible activities.

Table D.1: Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
New fence around the May 18, 1974 subsidence crater	Could have been erected as a safety measure to prevent mechanized units, on daytime or nighttime maneuvers, from accidently falling into the crater.	Could have been constructed immediately after the initial allegations of nuclear test preparations were made in order to prevent news reporters from descending into the hazardous crater area.	Could have been built to secure the site for new post-test experiments and training exercises that would prepare personnel for future nuclear tests.	Could have been erected as a safety measure to prevent Prithvi missile units, on daytime or nighttime maneuvers, from accidently falling into the crater.
Concentration of vehicle tracks next to the 1974 test site proceeding ~ 4 km towards the southeast	Could be the surface markings left by mechanized units practicing maneuvers in the open area. The concentration of vehicle tracks next to the 1974 test site could have been the assembly point.	Could be the tread marks left by military patrols that were sent out to keep the media away from conventional military areas. The concentration of vehicle tracks next to the 1974 test site could be a makeshift guard post.	Could be evidence of survey work for an underground nuclear test. The concentration of vehicle tracks next to the 1974 test site could be the planned ground zero. The tracks towards the southeast could be the planned cable route to the control point, which would be positioned in the same relative location as the 1974 control point.	Could be the tracks left by Prithvi transporter-erector-launchers (TELs) that performed off-road mobility tests in the open desert.

Table D.1: (Continued) Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
"...soon after the first (1974) explosion, grass and shrubs in the area were burnt..." Singh, *Business Standard*, 1/1/96, pp. 1, 3, + + + –	Since the 1974 test was conducted in the vicinity of established conventional test ranges, it is possible the area was burnt because of live munition firing during conventional exercises that happened after the 1974 nuclear test.	The grass and shrubs in the area may have been burnt by accident. Brush fires are common in arid regions with seasonal vegetation growth.	The grass and shrubs may have been burnt deliberately as part of a post-test experiment. The control burn could have been done in order to determine how abrupt ground motion and radioactive leakage from the 1974 nuclear test affected the regrowth of natural vegetation.	N/A. The Prithvi missile program did not even exist in 1974.
Two brush fires that happened after March 25, 1995	May have been caused by live munition firing in the area during conventional exercises. Alternatively, the fires may have been deliberately set to train troops for operations in a smoke-filled environment.	The fires started along the new security perimeter (see plate 16). The cause may have been two separate accidents that happened during the construction of the new security perimeter.	May have been set to clear vegetation before a planned nuclear test. The cleared ground could then be used as a study area to determine how abrupt ground motion and radioactive leakage affected the regrowth of natural vegetation.	May have been a fire control exercise to train personnel in brush fire containment following a Prithvi field test or launch mishap.

Table D.1: (Continued) Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
Biggest military exercises every witnessed by locals. Singh, *Business Standard,* 1/1/96, pp. 1, 3, + + + –	Could have simply been the largest conventional military exercises that have ever been staged in the Pokharan area.	N/A.	Could have been larger than usual because additional personnel and equipment were needed to prepare an underground nuclear test in conjunction with the routine conventional exercises.	Could have been larger than usual because Prithvi missile batteries and support units were added to the regular complement of army regiments.
Road link to/from military base located 4.0 km to the southwest.	Could be the main route for mechanized units to reach the military range for conventional exercises.	N/A.	Could exist so that the nearby mechanized units can provide physical security for the nuclear test site. The site is only 90 km from the border with Pakistan.	Could be used by the nearby mechanized units for participating in coordinated exercises with the Prithvi missile units.
New vehicle tracks to/from Nautala conventional target areas	Could be the tread marks left by artillery units based inside the secured area. Also could be tracks left by mechanized units from the military armor base.	N/A.	Could have been an indirect route for personnel and equipment to get to and from the nuclear test site via the conventional testing grounds. By entering and exiting the conventional ranges, the locals would have interpreted the activity as routine military exercises.	Could be the tread marks left by Prithvi transporter-erector-launchers (TELs) that performed off-road mobility tests in the open desert.

Table D.1: (Continued) Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
5/18/74 crater with cable line connecting it to the control point 4.8 km southeast of the ground zero	N/A.	N/A.	The crater was created by an underground nuclear explosion. The cable line was oriented perpendicular to the prevailing wind direction. The control point was used for firing the nuclear device, observing the explosion, and monitoring for radioactive release.	N/A.
Surface excavations for burial of nuclear warhead. Senator Cranston, 4/27/81, +	N/A.	N/A.	The Senator's description of surface excavations for burial of a nuclear warhead can only be construed as nuclear test preparations.	N/A.
Village leaders' reports of evacuation plans and new security perimeter. Bedi, *Indian Express*, 5/5/81, p. 1, + + +	N/A.	N/A.	The official notification of a four-day evacuation plan for nine neighboring villages could have been a safety measure to protect villagers from the earthquake-like ground shock and inadvertent radioactive release from a planned underground nuclear test.	N/A. The Prithvi missile program did not exist in 1981.

Table D.1: (Continued) Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
Nighttime operation of a machine that sounded like a drill. Bhattacharya, *Sunday Magazine*, May 9–15, 1982, pp. 12-15. + + +	N/A.	N/A.	The nighttime operation of a machine that sounded like a drill could have been a concerted effort to prepare the ground for underground nuclear testing.	N/A. The Prithvi missile program did not exist in 1982.
In the early 1980s, two holes were completed for future nuclear tests. Sidhu, *Jane's Intelligence Review*, 4/96, pp. 170-173. +	N/A.	N/A.	The two holes can plausibly be considered the result of the activity that was observed and reported in 1981 and 1982 by Senator Cranston, local villagers, and village leaders.	N/A.
Prithvi-1 mobility and preparation exercises, Sawhney, *Asian Age*, 12/19/95, pp. 1, 4. + + + +	N/A.	N/A.	N/A.	As described in the article, the activity around the 1974 nuclear test site could have been Prithvi-1 mobility and preparation exercises under field conditions.

Table D.1: (Continued) Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
Prospective impact points in several military operation areas located > 40 km and < 150 km away	N/A.	N/A.	N/A.	The March 1991 1:500,000 scale Tactical Pilotage Chart (H-8C) shows five military operation areas that could be used as impact points for Prithvi field tests. From the 1974 nuclear test site, the Prithvi-1 could reach targets in these areas at its minimum range (40 km) and maximum range (150 km).
Multiple perimeter barriers	N/A.	N/A.	At least four layers of security barriers surround the sites in the center of the military range. The reinforcement of these barriers may have been done to secure the sites for the delivery and underground placement of nuclear test devices.	At least four layers of security barriers surround the sites in the center of the military range. The reinforcement of these barriers may have been done to secure the sites for the delivery and temporary deployment of Prithvi-1 test missiles.

Table D.1: (Continued) Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
Laid out cables. Chari, *Hindustan Times*, 1/3/96, p. 11. + •	N/A.	N/A.	The cables could have been laid out to fire the nuclear test device and collect data from the nuclear explosion.	The cables could have been laid out to connect the field launch point with the Prithvi transporter-erector-launcher (TEL). Cables are routinely used worldwide for such mobile missile launches.
Identical rectangular structures at sites A and C connected to branches AF and CE which link with line EG and end at point G. (see plates 18 and 19)	N/A. The multiple perimeter barriers suggest that the activity inside the secured area was not routine conventional exercises.	N/A.	The linear traces could be cable lines connecting the control point (Point G) with the two shafts that were prepared in the early 1980s (the rectangular structures at sites A and C). As in 1974, the cable link (line EG) is oriented perpendicular to the prevailing winds, which would keep radioactive fallout away from the control point. (See figure 4)	The linear traces could be road transport links connecting the missile launch point (Point G) to the two buildings for housing the Prithvi missiles and volatile fuel supply (the rectangular structures at sites A and C). The road link (line EG) is 2.1 km long so test launches could be done at a safe distance from the basing areas. It is oriented perpendicular to the prevailing winds, which would keep the toxic exhaust plume away from the basing areas. (See figure 5)

Table D.1: (Continued) Table of Suppositions from the Collected Evidence on the Khetolai Military Range

Evidence	Conventional Military Exercises	Innocuous Activity	Nuclear Test Activity	Prithvi-1 Field Testing
Sites B and D connected to branches BF and DF which link with line EG and end at point G (see plates 18 and 19)	N/A.	N/A.	Site B is equidistant from the two inferred shaft locations (sites A and C). Thus, it could be a diagnostics station for recording the data that would be transmitted via cable from both explosion sites. Line BG could be a cable link from site B to the control point (Point G). Site D is located near the entrance to the central secured area. It could be a support base for nuclear test preparations with a new road link to the control point (Point G). (See figure 4)	Site B is equidistant from the two inferred Prithvi storage facilities and is connected to the inferred launch point (Point G). Thus, it could be the missile control point for coordinating the deployment of Prithvi units to the launch point, tracking the missile after launch, and communicating with the impact site. Site D is located near the entrance to the central secured area. It could be a support base for Prithvi field tests with a new road link to the launch point (Point G). (See figure 5)

NOTES AND REFERENCES

1. Tim Weiner, "India Suspected of Preparing for A-bomb Test," *The New York Times*, December 15, 1995, p. A6.

2. R. Jeffrey Smith, "Possible Nuclear Arms Test by India Concerns US," *Washington Post*, December 16, 1995, p. A17.

3. For remote sensing studies of the US Nevada Test Site, see Peter Zimmerman, Nancy Del Grande, and William McKinnis, "Persistent Changes in the Nevada Desert Resulting from Atmospheric Nuclear Tests," LLNL Report, UCRL-JC-105881, January 1991, pp. 1–14. 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** (1), February 1995, pp. 31–40.

For remote sensing studies of the former Soviet test sites, 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* (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** (18), 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** (5), 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** (2), 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 of the Chinese nuclear test site near Lop Nor, see Vipin Gupta, "Future Chinese Nuclear Tests on the Horizon," *Trust & Verify* (30), July/August 1992, pp. 2–3 (Presented at the 4th International Summer School on Science and World Affairs, August 28, 1992, Shanghai). 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** (8), August 1993, pp. 378–381. Vipin Gupta and Philip McNab, "Sleuthing from Home," *The Bulletin of the Atomic Scientists* **49** (10), December 1993, pp. 44–47. Vipin Gupta, "The Status of Chinese Nuclear Weapons Testing," *Jane's Intelligence Review* **6** (1), January 1994, pp. 31–35. Vipin Gupta, "Locating Nuclear Explosions at the Chinese Test Site near Lop Nor," *Science and Global Security* **5** (2), 1995, pp. 205–244. Vipin Gupta, *A Remote Sensing and Photogrammetric Study of the Chinese Nuclear Test Site*, PhD thesis (University of London, January 1996), pp. 1–264. Vipin Gupta and Donald Rich, "Locating the Detonation Point of China's First Nuclear Explosive Test on October 16, 1964," *International Journal of Remote Sensing* **17** (10), July 10, 1996, pp. 1969–1974.

4. "Non-Seismic Detection of Underground Nuclear Tests," *SIPRI Yearbook 1972: World Armaments and Disarmament* (Stockholm: Almquist and Wiksell, 1972), pp. 437–460. *Scientific and Technical Aspects of the Verification of a Comprehensive Test*

Ban Treaty (London: VERTIC, 1990), pp. 1–146. *Non-Seismic Technologies in Support of a Nuclear Test Ban* (Ottawa: Verification Research Unit, 1993), pp. 1–16. Laurence Nardon, "Test Ban Verification Matters: Satellite Detection," *Verification Matters* (7), November 1994, pp. 1–39. P Argo, R.A. Clark, A. Douglas, V. Gupta, J. Hassard, P.M. Lewis, P.K.H. Maguire, K. Playford, and F. Ringdal, "The Detection and Recognition of Underground Nuclear Explosions," *Surveys in Geophysics* **16**, 1995, pp. 495–532. Jasani, "Could Civil Satellites Monitor Nuclear Tests?," pp. 31–40. Gupta, "Locating Nuclear Explosions at the Chinese Test Site near Lop Nor," pp. 205–244.

5. R. Chidambaram and R. Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," *Peaceful Nuclear Explosions IV: Proceedings of a Technical Committee on the Peaceful Uses of Nuclear Explosions organized by the International Atomic Energy Agency*, January 20–24, 1975, pp. 421–436.

P.K. Iyengar, the Director of the Physics Group at the Bhabha Atomic Research Center (BARC) at the time of the Indian nuclear test, recently stated a slightly lower yield for the May 18, 1974 nuclear test. During the question and answer session that followed one of his recent presentations, he stated that the Indian nuclear test produced a yield of 8 kilotons TNT—"exactly what was predicted." P.K. Iyengar, "India's Nuclear Program: Past and Future," presented at the Henry L. Stimson Center, Washington DC, May 23, 1996.

The lowest quoted yield for the 1974 test is two kilotons TNT. According to a 1981 *Sunday Observer* article, "some sources at the BARC maintain that independent measurements by some scientists put the yield at Pokhran to be as low as 2,000 tons of TNT." Yogi Aggarwal, "India Makes Another Bomb," *Sunday Observer*, August 30, 1981.

6. R. Chidambaram and R. Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 434. An article in the *Illustrated Weekly of India* claimed a larger crater radius of 75 meters while a *Patriot* article reported a substantially smaller crater radius of only 9 meters. "UNI Correspondent Visits Pokhran A-Blast Site," *Patriot*, New Delhi, January 17, 1983, p. 7. Khushwant Singh, "Explosion in the Desert," *The Illustrated Weekly of India*, July 14, 1974, pp. 6–17.

R. Ramanna, the co-author of the January 1975 BARC report, was cited as the *Illustrated Weekly* source for the crater radius. Considering the *Illustrated Weekly* article was published just two months after the nuclear test, the '75 meter' crater radius may have been a preliminary measurement. Alternatively, it could represent the 'true crater' radius rather than the 'apparent crater' radius. The 'true crater' radius is defined as the crater that remains after all the ruptured material has been removed. The 'apparent crater' radius is defined as the crater as it appears after it was created. See Harry C. Saxe, "Explosion Crater Prediction Utilizing Characteristic Parameters," in Charles Fairhurst, *Rock Mechanics* (Oxford: Pergamon Press, 1963), pp. 273–306.

7. Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 432, 436. The caption under the photo of the crater states that the picture was taken from a helicopter "shortly after the experiment." At the end of the article, the authors provide more precise information on the aerial flight. Answering a conference participant's question on the time the crater was formed, the authors state that the helicopter observation was made "an hour after the experiment had taken place."

8. Aziz Haniffa, "US Warns Against Any Indian Nuclear Test," *India Abroad*, December 22, 1995, p. 14. Raj Chengappa, "Testing Times: India's Nuclear Policy," *India Today*, December 31, 1995, pp. 46–51.

9. The scale of the photos could be approximated from the photo distance between the tire tracks shown in the pictures. The photo distance could then be scaled to ground distance by estimating the perpendicular distance from the left tires to the right tires of the vehicle type that could have left the tracks on the ground.

10. "A Tremor...and a Roll," *Science Today*, A *Times of India* Publication, June 1974, pp. 20–21.

11. "UNI Correspondent Visits Pokhran A-Blast Site," p. 7. This article provided relative directions to the location of the May 18, 1974 crater: "Visitors have to suddenly veer off from the highway leading to Pokharan town and direct their vehicles on a seven km long narrow track that leads to the [May 18, 1974] site."

12. "Fears over Pokhran N-test Allayed," *Times of India*, May 20, 1993, p. 5.

13. Rahul Bedi, "Pokhran Full of N-test Talk," *Indian Express*, New Delhi, May 5, 1981, p. 1. "Villagers Expect Nuclear Test in Rajasthan," *Dawn*, Karachi, May 7, 1981, p. 14.

14. Damandeep Singh, "Heavy Military Build-Up Near First Nuclear Explosion Site," *Business Standard*, Delhi, January 1, 1996, pp. 1, 3.

15. Shubhabrata Bhattacharya, "Another Nuclear Blast at Pokhran?," *Sunday Magazine*, Calcutta, May 9–15, 1982, pp. 12–15.

16. *Bulletin of the International Seismological Centre*, May 1974, p. 91.

17. The systematic error estimate was based on the calculated systematic errors of Chinese nuclear tests that also registered as magnitude 4.9 seismic events. See figure 6 and table D.1 in Gupta, "Locating Nuclear Explosions at the Chinese Test Site near Lop Nor," p. 222, 239. The size of the random error component was cited from Roger Clark and John Baruch, "Verification of a Comprehensive Test Ban," in Frank Barnaby, ed., *A Handbook on Verification Procedures* (London: MacMillan Press, 1990), p. 88.

18. The 1:250,000 map sheets of northwestern India (Series U502, Edition 1-AMS) were obtained from the Earth Sciences Map Library at Stanford University.

19. Jasani, "Civil Observation Satellites and Arms Control Verification," pp. 68, 96.

20. Ground sample distance (GSD) is the length and width of each pixel in a digital image projected onto the ground. The size of the GSD is a key factor in the amount of spatial detail in an image. See Peter Zimmerman, "A New Resource for Arms Control," *New Scientist* **123**(1683), September 23, 1989, p. 40. M.R.B. Forshaw, A. Haskell, P.F. Miller, D.J. Stanley, and J.R.G. Townshend, "Spatial Resolution of Remotely Sensed Imagery: A Review Paper," *International Journal of Remote Sensing* 4(3), 1983, pp. 497–520.

21. Senator Alan Cranston, "Nuclear Arms Race in South Asia Endangers US Security Interests," *Congressional Record*, US Senate, April 27, 1981, pp. 7375–7377.

22. Cranston, "Nuclear Arms Race in South Asia Endangers US Security Interests," p. 7375.

23. Bedi, "Pokhran Full of N-test Talk," p. 1.

24. Bhattacharya, "Another Nuclear Blast at Pokhran?," p. 13. AFP ran a follow-on story based on the *Sunday Magazine* article. "Indian Weekly Reports Pokhran Site Sealed Off, Predicts H-Bomb Test," AFP, May 10, 1982.

25. W.P.S. Sidhu, "India's Nuclear Tests: Technical and Military Imperatives," *Jane's Intelligence Review* **6** (4), April 1996, pp. 170–173.

26. Weiner, "India Suspected of Preparing for A-bomb Test," p. A6.

27. Smith, "Possible Nuclear Arms Test by India Concerns US," p. A17.

28. The article did not specify the exact location of these four ranges relative to Pokharan. M.D. Nalapat, "Defense Officials Upset over Report on N-test," *The Times of India*, Bombay, December 18, 1995, p. 1.

29. "Using a Pretext of the Nuclear Test," *Jansatta*, Delhi, December 19, 1995, p. 6.

30. Pravin Sawhney, "Preparations at Pokharan Site Reportedly for Missile Test," *The Asian Age*, Delhi, December 19, 1995, pp. 1, 4. Pakistani officials reacted to the *Asian Age* article by taking 'strong exception' to any Indian plans to test the Prithvi missile. " 'Strong Exception' taken to Indian Missile Test Reports," Islamabad Radio Pakistan Network, 1400 GMT, December 19, 1995.

31. Greg Gerardi, "India's 333rd Prithvi Missile Group," *Jane's Intelligence Review* **7** (8), August 1995, pp. 361–364.

32. The Prithvi reportedly uses a 50-50 mix of xylidene and triethylamine as rocket fuel and red fuming nitric acid as the oxidizer. See Manoj Joshi, "Vehicles of War: The Prithvi, the MBT, and the ALH," *Frontline*, September 25, 1992, p, 122. "Prithvi Surface-to-Surface Missile," *World Missiles Briefing* (Teal Group Corporation, April 1996), pp. 1–4.

These substances are toxic and can cause serious burns. The red fuming nitric acid is particularly hazardous because it reacts spontaneously with many organic substances and the fumes are poisonous. Missile crews have to take special precautions to handle the volatile materials safely and avoid direct contact with the fuel, oxidizer, and exhaust plume. See George Sutton, *Rocket Propulsion Elements: An Introduction to the Engineering of Rockets* (New York: John Wiley and Sons, 1986), pp. 168–182.

33. Prem Shankar Jha, "Maintaining India's Nuclear Option," *The Hindu*, Madras, December 30, 1995, p. 12.

34. P.R. Chari, "Reports of Test Forcing Nuclear Decision," *The Hindustan Times*, Delhi, January 3, 1996, p. 11.

35. Singh, "Heavy Military Build-Up Near First Nuclear Explosion Site," pp. 1, 3.

36. A journalist who visited the 18 May 1974 ground zero in 1983 also noted the presence of "grazing goats" nearby. "UNI Correspondent Visits Pokhran A-Blast Site," *Patriot*, p. 7.

37. Drilling debris from shaft construction can be used as stemming material. India utilized this recycling process for the May 18, 1974 test. See Chidambaram and Ramanna, "Some Studies of India's Peaceful Nuclear Explosion Experiment," p. 424.

38. Even the *Asian Age* article that described Prithvi field test preparations placed the location of the activity relative to the May 18, 1974 explosion site.

39. Although KVR-1000 imagery is typically sold with the claim of providing a two-meter ground sample distance (GSD), this specific image appeared to have been processed at a slightly coarser spatial resolution. This was inferred from the inability to detect a single vehicle in the 40 x 40 km image. Vehicles are readily detectable at a two-meter GSD so this image must have been processed at a slightly higher GSD, which made the vehicles indistinguishable from the surrounding environment. See Vipin Gupta, "New Satellite Images for Sale," *International Security* **20** (1), Summer 1995, pp. 96-97, 101–103.

40. There was another reason for selecting this SPOT image. It was the most current "before" image that could be used to detect and identify any activity that could have occurred later in 1995.

41. Available maps supported the *Sunday Magazine* claim that Malka village no longer exists. The 1955 1:250,000 US Army Map Service map sheet NG-42-04 from Stanford University showed Malka village, but the 1985 1:250,000 Joint Operations Graphic NG-42-04 from the US Library of Congress did not.

42. The authors requested a complete list of cloud-free KVR-1000 images of the area. Sovinformsputnik—the distributor of KVR-1000 imagery—did not provide such a list, but did state that this single image was available for purchase.

43. Other large circular features were found in the KVR-1000 image. However, closer examination of these features revealed that all were film blemishes.

44. *Bulletin of the International Seismological Centre*, May 1974, p. 91.

45. The matching azimuthal orientation of the four physical features also independently verified that the helicopter photo of the crater was indeed taken in the early morning.

46. The two maps were the 1955 1:250,000 US Army Map Service map sheets NG-42-04 and NG-42-08.

47. The May 24, 1992 KVR-1000 image did not show Malka village. This verified the *Sunday Magazine* claim that the village was abandoned.

48. The archives of declassified satellite imagery were searched using the Global Land Information Service (http://edcwww.cr.usgs.gov/glis/glis.html). The geographic location of the May 18, 1974 crater was the only parameter that was used in the data search.

49. The coarse outline of Malka village was found in the KH-3 image and correlated with the 1955 1:250,000 US Army map location of the village (see plate 6 inset). Since the KH-3 image was acquired at approximately the same resolution (10 meters) as the SPOT panchromatic imagery, Malka village would have been detectable in the recent SPOT and KVR-1000 imagery (see plates 3 and 7). Yet, no evidence of Malka village was observed. Thus, the *Sunday Magazine* claim was correct; the village was abandoned.

50. Bedi, "Pokhran Full of N-test Talk," p. 1. "UNI Correspondent Visits Pokhran A-Blast Site," *Patriot*, p. 7.

51. Like the right triangular feature in area 1, the fenced reservation was identified by the presence of natural, healthy vegetation growing in its interior and the absence of farming or livestock grazing.

52. Bhupendra Jasani, "Arms Control Verification By Satellite," *International Defense Review* **23** (6), June 1990, pp. 643–646.

53. "For example, an interpreter can always spot a military armored unit by its associated series of bowling-alley-like lanes, which are actually tank firing ranges." Dino Brugioni, "The Art and Science of Photoreconnaissance," *Scientific American* **274** (3), March 1996, pp. 78–85.

54. This assessment is consistent with the December 18, 1995 *Times of India* article, December 19, 1995 *Asian Age* article, and December 19, 1995 *Jansatta* article, which describe army exercise ranges in the Pokharan area. Nalapat, "Defense Officials Upset over Report on N-test," p. 1. Sawhney, "Preparations at Pokharan Site Reportedly for Missile Test," pp. 1, 4. "Using a Pretext of the Nuclear Test," p. 6.

55. The largest, irregularly shaped crater at area 4 had a maximum breadth of 70 meters.

56. This conclusion is consistent with the May 9–15, 1982 *Sunday Magazine* article, which claimed that Nautala village was evacuated around 1971 to make the land available to the Indian army. Bhattacharya, "Another Nuclear Blast at Pokhran?," p. 12.

57. This assessment is consistent with the December 19, 1995 *Asian Age* article, which describe an artillery firing range and air force range in the Pokharan area. It is also consistent with the *Times of India* and *Jansatta* description of army exercise ranges in the Pokharan area. Sawhney, "Preparations at Pokharan Site Reportedly for Missile Test," pp. 1, 4. Nalapat, "Defense Officials Upset over Report on N-test," p. 1. "Using a Pretext of the Nuclear Test," p. 6.

58. Singh, "Heavy Military Build-Up Near First Nuclear Explosion Site," *Business Standard*, pp. 1, 3. "UNI Correspondent Visits Pokhran A-Blast Site," *Patriot*, p. 7.

59. Plate 13 clearly shows that the fenced perimeter was triangular in March 1995 and not rectangular as described in May 1981. This means that either the fence lines were moved to the triangular configuration during the intervening 14 years, or the deputy leader of Loharki incorrectly described the area enclosed by the 1981 fence line as rectangular.

60. There are also trails between Khetolai village and the south entrance. Villagers may use these paths to get to and from menial jobs inside the secured area. An additional or alternative possibility is that military personnel stationed inside the perimeter use the trails to visit Khetolai.

61. A simple, mirror stereoscope was used to view the height of features in the SPOT images.

62. Using SPOT panchromatic imagery, height differentials as low as 20 meters can be resolved for mapping purposes provided the stereo images are high quality. A vertical resolution of 20 meters means that excavated mounds of sand and earth would have to be quite large to be detectable in SPOT stereo.

Consider the shaft for the May 18, 1974 nuclear test as an example. That test was conducted in a cylindrical shaft that was reportedly 6 meters in diameter and 107 meters deep. The construction of such a shaft would have displaced 3025 m^3 of earth (Volume = $\pi r^2 h$). If the excavated material was dumped into a single pile, it would form a cone with an angle of repose of approximately 40 degrees. The volume of the cone would equal the volume of the cylindrical shaft and the height of the cone would be a function of the base:

$$h = \frac{1}{2} b \tan(\theta)$$

$$V = \frac{1}{3}\pi\left(\frac{b}{2}\right)^2 h = 3025$$

where

h—height of the pile
b—base of the pile
θ—angle of repose
V—volume of the cone

Based on these physical parameters, the pile would be 30 meters across and 13 meters high. Although such a pile would be quite large and cover a lot of ground (6-9 SPOT panchromatic pixels), it would still have a height differential below the threshold of vertical resolvability. See E.I. Theodossiou and I.J. Dowman, "Heighting Accuracy of SPOT," *Photogrammetric Engineering and Remote Sensing* **56** (12), December 1990, pp. 1643–1649. Joseph Bowles, *Foundation Analysis and Design* (New York: McGraw Hill, 1982), p. 60."A Tremor...and a Roll," pp. 20–21. Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 423.

63. The SPOT time-lapse sequences showing changes between March 25, 1995 and March 2, 1996 were recorded on videotape.

64. Liquid effluent was also initially considered as a possible cause of the vegetation damage. However, it was later ruled out because of the shape of the denuded area. Spilled on sandy desert terrain, liquids appear as rivers and pools rather than plumes. This was established empirically in the Kuwaiti desert following the 1991 Gulf War. Landsat TM images show damaged wellheads as point sources of rivers and lakes of oil. See Peter Zimmerman, "The Use of Civil Remote Sensing Satellites During and After the 1990-1991 Gulf War," in John Poole and Richard Guthrie, *Verification Report 1992* (London: VERTIC 1992), pp. 230–240.

65. For the historical ground and aerial photos from the May 18, 1974 nuclear test, see Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," pp. 430, 432.

66. The parabolic sand dunes in this area point in the direction of the winds that created them (see plate 18). Once formed, the sand dunes retain their shape and do not migrate, as proven by the identical sand dune patterns in the December 12, 1961 KH-3 image and the March 25, 1995 SPOT image (see plates 6 and 7). See Thomas M. Lillesand and Ralph W. Kiefer, *Remote Sensing and Image Interpretation* (New York: John Wiley and Sons, 1987), p. 499.

In the Rajasthan Desert, the prevailing winds blow from the southwest between July and September. From October to June, the prevailing winds come from the northeast. See *Encyclopedia Britannica* **18**, 1974, pp. 206–207.

67. The connecting, unpaved roads also appear thicker and brighter relative to the adjacent land, indicating increased vehicle traffic.

68. This was demonstrated empirically in a Russian ALMAZ-1 radar image of the main base and nearby airdrop marker at the Chinese nuclear test site near Lop Nor. See Gupta, "The Status of Chinese Nuclear Weapons Testing," pp. 34–35.

69. This noise is inherent in all SAR imagery. See Lillesand and Kiefer, *Remote Sensing and Image Interpretation*, p. 499.

70. The circular arc was found by registering the Radarsat image to the March 2, 1996 SPOT image, flickering between the two images, and visually matching the shapes of features shown in both images. The flicker sequence was recorded on videotape.

71. A supposition is the act of "assuming something, without reference to it being true or false, for the sake of argument or for the purpose of tracing the consequences." See Random House Dictionary of the English Language (New York: Random House, 1969), p. 1430.

72. Jon Barwise and Eric Hammer, "Diagrams and the Concept of Logical System," in D.M. Gabbay, *What is a Logical System?* (Oxford: Clarendon Press, 1994), pp. 79–83.

73. The shafts at the US Nevada Test Site were positioned at the center of the site's perimeter. See US Congress, Office of Technology Assessment, *The Containment of Underground Nuclear Explosions*, OTA-ISC-414 (Washington DC: US Government Printing Office, October 1989), p. 66.

74. US Congress, *The Containment of Underground Nuclear Explosions*, p. 66. For information on the time response degradation of specific cables as a function of length and signal frequency, see Bernard Matisoff, *Wiring and Cable Designer's Handbook* (Blue Ridge Summit, PA: TAB Books, 1987), pp. 154–157.

75. If Point G is a field launch point, one would expect to see wide-radius turn loops in the immediate vicinity. Such loops would most likely be needed to accommodate Prithvi TELs. Smaller missiles are known to require such turning tracks. This is illustrated in an archived aerial image of an SA-2 surface-to-air missile site in Cuba. That SA-2 missile type was seven meters in length—approximately 1.5 meters shorter than the Prithvi. See Brugioni, "The Art and Science of Photoreconnaissance," p. 79. Barton Wright, *World Missile Database Volume I: Soviet Missiles* (Lexington: Lexington Books, 1986), p. 549. "Prithvi Surface-to-Surface Missile," p. 2.

76. Cables are routinely used for mobile missile launches. See Steven Zaloga, "The 'Scud' Ballistic Missile," *Asia Pacific Defence Review*, Nov/Dec 1993, p. 20.

77. "Prithvi Surface-to-Surface Missile," p. 2.

78. According to the 1991 1:500,000 scale Tactical Pilotage Charts of Pakistan (H-8A through H-8D), a handful of small towns and villages would be within reach of Prithvi-1 from the Khetolai military range. For a list of high-value targets in Pakistan, see Harbir K. Mannshaiya, "India's Prithvi: Government Held Hostage by Its Own Missile," *International Defense Review* **28** (8), August 1995, pp. 23–25.

79. "Prithvi Surface-to-Surface Missile," p. 3. Mannshaiya, "India's Prithvi: Government Held Hostage by Its Own Missile," p. 23. Gerardi, "India's 333rd Prithvi Missile Group," pp. 361–362.

80. 1:500,000 scale Tactical Pilotage Charts H-8B and H-8C, Defense Mapping Agency Aerospace Center, St. Louis, March 1991.

81. Gupta, "New Satellite Images for Sale," pp. 102–103.

82. News groups and web sites on the Internet are promising avenues for connecting with these alternative information sources.

83. For all CTB-relevant technologies, the monitoring of a suspect test site could be intensified by increasing the sampling frequency and scrutinizing all signals that emanated from the area. The various commercial imaging satellites could be tasked to acquire images every time the suspect area came into view. The infrasound sensors could regularly search for acoustic waves from the potential test area. The radionuclide sensors could be deployed in closer proximity to the prospective explosion site and sampled at a greater frequency. And the signals collected by the seismic arrays could be sent through a phased array processing routine that searched for signals from the suspect site. For all of these technologies, the collected data could be interpreted in near real-time to determine what normal signals came from the area and whether there were any anomalous signals that could be interpreted as nuclear test activity.

84. Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 432.

85. Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 436.

86. *The American Ephemeris and Nautical Almanac for the Year 1974* (Washington DC: US Government Printing Office, 1974), p. 27.

87. Peter Duffett-Smith, *Practical Astronomy with your Calculator* (London: Cambridge University Press, 1979), pp. 10–11.

88. The local meridian is a plane that contains the Earth's poles and the point directly above the observer's location (i.e., the zenith).

89. The hour-angle, elevation, and azimuth calculations were done using the sun's equatorial coordinates at a time that differed by 3.58 hours from the photo acquisition time. This introduced a small error—on the order of a few minutes of time—into the result because the Earth moved slightly (<.25°) along its orbit during the time interval. For the determination of the shadow direction in the helicopter picture, this amount of error was insignificant and consequently was neglected. Comparable temporal errors of 2–3 minutes from atmospheric refraction were also not taken into account for the same reason. See Duffett-Smith, *Practical Astronomy with your Calculator*, p. 55.

90. Duffett-Smith, *Practical Astronomy with your Calculator*, p. 24.

91. Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," pp. 421–436.

92. Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 430.

93. Chidambaram and Ramanna, "Some Studies on India's Peaceful Nuclear Explosion Experiment," p. 425.

94. If none of the radioactive monitoring stations fit the camera and shadow geometry shown in plate B.1, it would indicate that the control point location was not included in the map of deposition trays and health physics survey teams.

95. *Bulletin of the International Seismological Centre*, May 1974, p. 91.