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STRENGTHENING IAEA SAFEGUARDS USING HIGH-RESOLUTION COMMERCIAL SATELLITE IMAGERY*

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ABSTRACT

The proliferation of nuclear weapons poses great threat to international peace and security. How to strengthen the non-proliferation regime has become a central question. In May 1997, the IAEA Board of Governors adopted the Additional Safeguards Protocol to improve its ability to detect the undeclared production of fissile material. This new strengthened safeguards system has opened the door for the IAEA to use of all types of information, including the potential use of commercial satellite imagery. We have therefore been investigating the feasibility of strengthening IAEA safeguards using commercial satellite imagery. This paper explores the new roles of high-resolution commercial satellite imagery to monitor the nuclear proliferation. Based on our analysis on a number of one-meter resolution IKONOS commercial satellite images of nuclear facilities, we found that the new high-resolution commercial satellite imagery would play a new and valuable role in strengthening IAEA safeguards.

INTRODUCTION

After the discovery of Iraq's clandestine nuclear weapon program and North Korea's noncompliance with its safeguards obligations, the IAEA determined that the traditional safeguards system was ineffective for detecting undeclared nuclear facilities and activities. In May 1997, the IAEA Board of Governors adopted the Additional Safeguards Protocol to expand existing safeguards agreements and improve the IAEA's ability to detect the undeclared production of fissile material[1]. This new strengthened safeguards system has opened the door for the IAEA to use of all types of information, including the potential use of commercial satellite imagery.

Given the dramatic increase in commercial satellite imagery capabilities, as case studies, this paper explains in details how commercial observation satellites could be used for strengthening IAEA safeguards. This work will focus on technical aspect of uses of commercial satellite imagery to detect undeclared nuclear facilities. The Legal, political and financial issues are not discussed here.

HIGH-RESOLUTION COMMERCIAL SATELLITE IMAGERY

Since the early 1960s, US and the USSR/Russia use their satellites (as NTM) to identify and monitor each other and other countries' nuclear facilities and activities. Starting in 1972, these

* The views expressed in this paper are the author's alone and do not necessarily represent any government policy.

satellites as well as other national technical means were used to verify strategic arms control agreements, including SALT I and the Anti-Ballistic Missile Treaty. The current capabilities of these systems are estimated to have 10cm resolution. However, not all countries have access to such capabilities, and they are not willing to share widely the information from such satellites.
However, lower resolution observation satellites were made available for civilian purposes, starting with the launch of the US Landsat-1 (with 80 meters resolution) in 1972. Through 1980s and 1990s, a variety of commercial satellite images (including 10m- resolution panchromatic images from France's SPOT, 30m-resolution images from Landsat 4 and 5; 5.8m- resolution images from India's IRS-1C and -1D, and some 5m-resolution images from Soviet/Russia satellites) are sold to the public. Particularly, around 90s early, the possible roles of these medium-resolution images to monitor the nuclear proliferation were explored[2]. However, it was estimated that there was very limited and moderate roles to identify nuclear production facilities and to monitor the operating status of nuclear facilities on by these poorer resolution images.

The capabilities of commercial observation satellite are being dramatically improved .On 24 September 1999, the US firm Space Imaging launched the first such satellite—IKONOS—with a 1m resolution panchromatic sensor and a 4m a resolution multispectral sensor. The United States has now licensed Space Imaging to launch a satellite that can provided 0.5-meter resolution images. Space imaging plans to launch such a satellite in 2004. Also US firm EarthWatch plans to launch QuichBird2 with 0.5-meter resolution later this year. Moreover, the Russian firm Sovinformsputnik has started to sell Russian 1m ground resolution satellite images to customers all over the world. Other companies such as the US companies Orbimage, and the Israeli firm West Indian Space , plan to launch their high-resolution commercial imaging satellites soon. It is expected that a dozen or so such satellites from several different countries will be in orbit over the next few years. All of these new-generation commercial observation satellites have: 1m or better resolution; relatively short revisit intervals (one to five days); fore-and-aft and side-to-side pointing capability; stereo imaging; huge on-board data storage capacity; and the ability to deliver images to customers in hours or days.

Unlike the medium resolution satellite imagery, the capabilities of these new high- resolution commercial satellites are good enough to detect and identify the major visible characteristics of nuclear production facilities and sites. Furthermore, unlike the classified spy satellite photos limited to few countries, the commercial satellite imagery is commercially available to anyone who wants to purchase it. Therefore, commercial satellites are opening new opportunities that each state, international organizations, and non-governmental groups could use the commercial images to play a more proactive role in monitoring the nuclear activities in related countries and verifying the compliance of non-proliferation agreements. This could help galvanize support for intensified efforts to slow the pace of nuclear proliferation.

IDENTIFYING DEDICATED NUCLEAR FACILITIES AND SITES

One important way for international community to monitor the nuclear proliferation is to identify the undeclared nuclear facilities and sites. The new satellites have the advantages of searching for and locating clandestine nuclear sites by surveying the whole globe with regular and frequent visits and with fine resolution. To produce fissile materials(plutonium and highly-enriched uranium) for weapons, a country would operate dedicated plutonium-production reactors and the associated reprocessing plants or uranium enrichment plants. These plants would have some characteristic visible features which can be seen from 1m-resolution satellite images.

Figure 1 shows a 1-meter color IKONOS image acquired in July 2000 of an area containing the two oldest Russian plutonium-production reactors at Seversk (Tomsk-7). The two sizable reactor containments, cooling towers and high stacks are clearly visible. The six towers at the upper left and the eight towers at the bottom right are, in all likehood, associated with the EI-2 (1200MWt) and ADE-3(1900MWt) reactors respectively. And both reactors were closed in 1990 and 1992 respectively. Also, from a 1m-resolution IKONOS satellite image (acquired in February 2000) over Pakistan's Khushab plutonium production reactor[3], the sizable reactor containment (dome), the mechanical-draft cooling tower (with eight vents), and the high stack at the reactor site are clearly seen. It should be noted that this 1m-resolution image shows much more details of the reactor facilities than that a released 10m-resolution SPOT image (acquired May1992) over the same site which cannot resolve the dome, cooling towers and high stack these specific visible features of a reactor. So the medium resolution images provide less direct and convincing evidences for the assumed reactor site. However, this 1m-resolution image provides undoubtedly the direct evidence of the facilities for Pakistan growing nuclear capabilities.

Figure 2 shows a 1m-resolution color IKONOS image of Indian Trombay reprocessing plant that used to support the Indian nuclear weapons program. The reprocessing building and the high stack (for discharge of gaseous fission products released during the reprocessing) are clearly observable in the image. This medium scale reprocessing plant started its commission in 1964, shut down in 1974, and was enlarged and re-opened in the early 1980s. This plant reprocess spent fuels from Cirus and Dhruva reactors with a capacity of about 50 tonne per annum. It is believed this facility provided plutonium for nuclear explosions in 1974 and 1998 nuclear test. Also the image shows clearly the trucks that parking in the shipment port. These trucks are presumably used to ship cut-spent fuel rods from the Cirus reactor. It should be noted that the reprocessing building at the Trombay site is smaller than those large scale ones, such as the reprocessing plant at Seversk (Tomsk-7). From an image taken by a CORONA satellite on September 15, 1971of the Tomsk-7 reprocessing plant[4], the long (more than 800-meter long) "canyon-like" building (typical of large reprocessing plants) and the very high stack (readily distinguished by its long shadow) can also be seen clearly.

Based on the analysis of the 1m-resolution IKONOS commercial satellite images and declassified US Corona satellite images(2-3m resolution), the key fissile material production facilities would have some visible infrastructure signatures for high-resolution satellite imagery (see Table 1) [5]. In the absence of elaborate concealment measures, all these characteristic visible features of undeclared nuclear sites would be detected and identified using one-meter resolution satellite images. However, for smaller scales such as gas centrifuge facilities and Laser enrichment facilities which could be a preferred way for future proliferants, they will have much less obviously observable characteristic as a GDP have for satellite images. The identification of a centrifuge enrichment plant(CEP) had to rely heavily on other collateral information. However, the recently 1m resolution IKONOS image of Pakistan Khuhuta CEP provides much more details than the once released a 10m- resoluition SPOT images did[6]. Besides its security perimeter, the image can identify the enrichment buildings at south and north production area, from which one could estimated the production scale.

In addition, dedicated heavy water production facilities providing heavy water for the dedicated heavy water production reactor would also have visible features for high-resolution satellite imagery. A proliferant could use heavy water production reactors in which plutonium can be bred from natural uranium. The importance of heavy water to a nuclear proliferator is that it provides one more route to produce plutonium for use in weapons, entirely bypassing

uranium enrichment and the entire related technological infrastructure. Also heavy-water-moderated reactors can be used to make tritium. As such, the production of heavy water has always been monitored, and the material is export controlled. Figure 3 show a 1m-resolution color IKONOS satellite image of a heavy water plant at Pakistan's Khushab reactor site. This plant likely uses the standard process to produce heavy water as the Kota plant in India and the Bruce Heavy Water Plant Canada. For such a plant, it typical uses a dual-temperature water-hydrogen sulfide exchange process (Girdler Sulfide process--GS) as a primary process to enrich the heavy from 0.015% deuterium to enrichment between 10% and 30% deuterium, and finally use water distillation method to get reactor grade heavy water (>99.7% D)[7]. The cascade for the GS process usually contains a series of stages in which consists of couple or few exchange columns. Each exchanges columns is typical of a few tens meter high and few meter diameter[8]. Also GS process typical includes a high tower (several tens meters) used to discharge to environment the poisonous H_2S gas leaked from the process. In addition, because only about one-fifth of the deuterium in the plant feed water becomes heavy water product, the production of a single pound of heavy water requires 340,000 pounds of feed water. Consequently, a number of water storage tanks would be required .In the image; we can see clearly a row of exchange columns (at least four) for the GS process and the high tower for discharge pious H_2S gas. The three big tanks possibly used to pre-treat or purify water. Based on the analysis, we can expect that the characteristic features of a heavy water plant are identifiable to 1m-resolution satellite images.

Finally, the constructions of all these nuclear material production facilities include a great many activities, such as the shipment of heavy components. Large trucks should be big enough to be identified in one-meter resolution images at visible bands. Such activities would take place for a considerable period of time[9]. So commercial satellites with several days' revisit time and one-meter resolution could detect these facilities and activities.

Table 1. The infrastructure features of dedicated nuclear material production facilities that might be observable from high resolution satellite imagery

Nuclear facilities	Observable characteristic features
Reactors	cooling towers or a natural water body(with intake and discharge port); a high narrow stack (or its shadow); a reactor building; security perimeter ; railroads, roads; an isolated site, etc.
Reprocessing plants	a very high stack(or its shadow); a long "canyon-like" building(or with vent); some holding ponds or reservoirs for waste or sludge; security perimeter ; railroads, roads; an isolated site, etc.
GDPs	large-area (roof) process buildings (the roof of most building have ventilation shaft);cooling towers or a nearby river or lakes ; a nearby fossil fuel power plant; large electric switchyard(substation) ;waste management and disposal facilities ; security perimeter ; railroads, roads; an isolated site, etc.

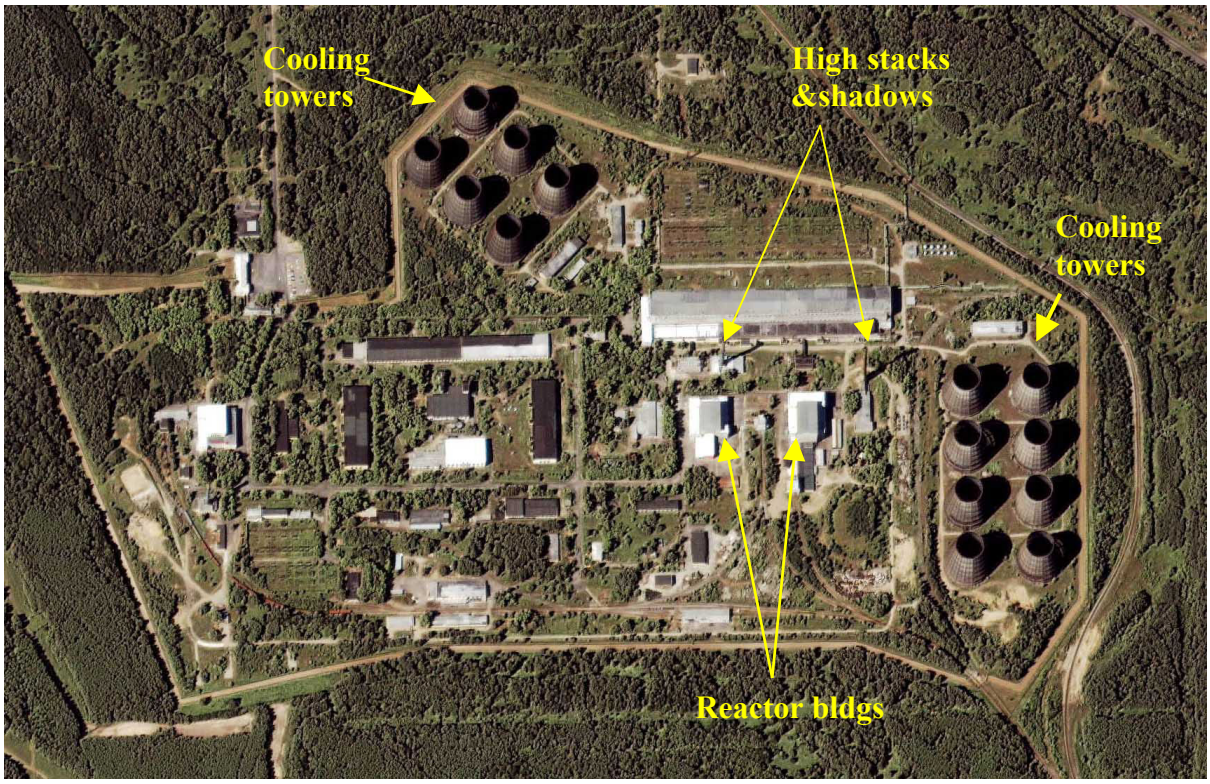

FIG.1. 1m-resolution IKONOS satellite image (captured July 2000) of site of plutonium production reactors EI-2 and ADE-3 at Tomsk-7, Russia. Credit:Spaceimaging.com.

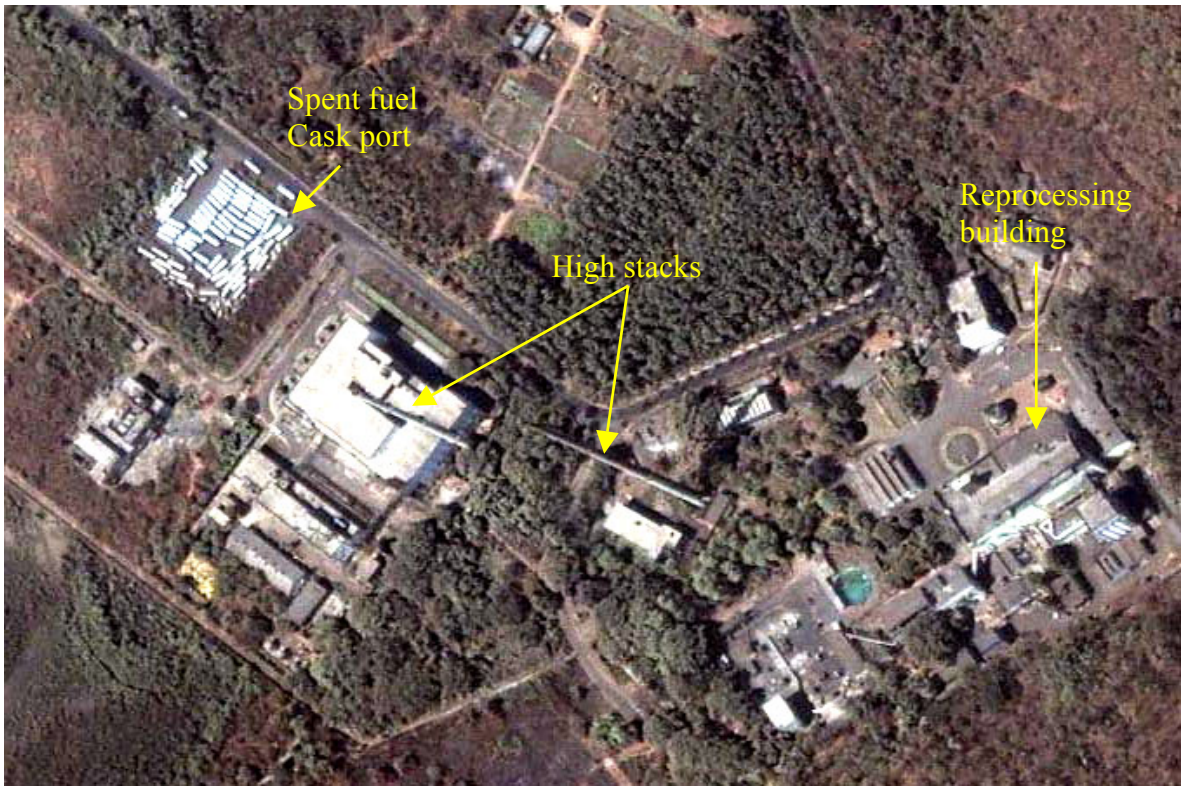

FIG.2. 1m-resolution IKONOS image (captured February 2000) of the reprocessing plant at Trombay, India. Credit:Spaceimaging.com.

FIG.3. 1m-resolution IKONOS image (captured February 2000) of the heavy water production facilities near Khushab reactor site, Pakistan. Credit:Spaceimaging.com.

FINDING UNDERGROUND NUCLEAR FACILITIES?

Facing this new challenge of widely available high-resolution satellite imagery, some states in the future could take deceptions and antisatellite-imaging countermeasures to make their dedicated nuclear facilities hide. For example, one approach to concealment would be locate the nuclear facilities amid a major industrial site which could make satellite imagery too difficult to detect them. However, it would raise a variety of security and safety concerns, and to date, no state seems to have taken up this challenge. Another possible approach would be build the nuclear facilities underground. However, the cost of such clandestine program would be substantially higher. Also such program will involve many personnel, instrument and activities, in a more and more transparent community, it will be more difficult to keep the secret. Once get information of the program, commercial satellites will easily target the suspect site.

Moreover, based on the experience of a few known underground nuclear facilities, there are still some observable characteristic features for high-resolution satellite imagery. Consider, for example, the Russian plutonium production facility at Krasnoyarsk-26, where three plutonium production reactors, a reprocessing plant, and associated storage and processing facilities were built entirely inside a granite mountain on the side of Yenisey River. From the declassified Corona satellite images (about 2m, 3m- resolution)[10], it can clearly see the security fence around the site. The railroads, roads and the entrances to the underground site can also visible. It can also see the cooling water reservoirs nearby the river, which could be used to provide cooling water piped in from the Yenisey River for the reactors. The discharge point of the cooling water could be detected by the visible photos through the absence of ice on the

river in the wintertime. Also it can be identified some ventilation shafts and a high stack used to release the gaseous fission products from reactor or reprocessing plant. Also, it can detect the underground reprocessing waste injection wells to the northwest of the underground complex.

Another underground dedicated nuclear facility is the reprocessing plant at Israel's Dimona nuclear complex. From the 2m-resolution IKONOS image (taken on July4, 2000) and the declassified images over this site[11], it can clearly see the high stack associated with the reprocessing plant. Also the security fences around the complex, the reactor building(dome) and mechanical cooling towers(with two vents) are clearly visible in the images. This underground reprocessing plant is reported completed in the mid-1960s, with probably reprocessing capacity to produce plutonium for five to ten nuclear warheads a year. The declassified Corona Images taken in 1963 and 1965 also reveal a large excavation, which could contribution to the construction of the reprocessing plant. From the later Corona images acquired in 1971,there was no such excavation, and the site covered with other landscapes[12]. These images can show the underground construction of the facilities.

Finally, the proliferant could build clandestine nuclear facilities inside or near the declared nuclear site. It should be easier to detect these facilities than those of the unknown sites, because the satellite would target and observe these declared sites frequently. If some new undeclared buildings and facilities appear in these areas or some changes have taken place, the satellite can detect these activities by comparing the early photos and later photos. Then it could trigger the IAEA to conduct on-site special inspections. Furthermore, besides these characteristic features observable on the satellite images in the visible band, when these nuclear facilities operate, discharged heat effluents could be detected by thermal infrared imaging[13].

CONCLUSION

These case studies show that the new high-resolution commercial observation satellite imagery would play a new and valuable role to monitor the nuclear proliferation. The 1m - resolution satellite images would be useful for the detection and identification of the nuclear production facilities through their infrastructure signatures. New changes at known nuclear site are readily observable.

Thus, commercial satellite imagery could provide the targets for on-site inspections; this would be especially useful for identifying undeclared sites. It could trigger a special inspection with on-site sampling and visual observation. The satellite imagery could also be used to confirm information acquired by the agency from other sources. Conversely, to assist in identifying suspect facilities, other sources could be used to narrow the targets for satellite observation. However, it should be noted that, satellite imagery cannot do everything. For example, satellite imagery would be less useful for verifying the case of declared operating fissile material production facilities. A proliferant in the future could take deceptions and antisatellite-imaging countermeasures to make their dedicated nuclear facilities hide. In general, commercial satellite imagery cannot be expected to be a stand-alone verification method, but should instead be seen as one useful tool in the strengthened safeguards and the integrated safeguards system.

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