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Imagery Analysis

Perhaps the most comprehensive volume extant on the methodologies and processes that constitute the art and science of imagery analysis is the *Manual of Photographic Interpretation*, Second Edition, American Society of Photogrammetry and Remote Sensing, 1998, ISBN 1-57083-039-8, Warren R. Phillipson Editor-in-Chief. (This edition drew heavily from the First Edition, 1960. The late Professor Dr. Robert N. Colwell, whom this author had the privilege of knowing as both mentor and friend, edited that edition.) For more information on imagery analysis in particular and the geospatial sciences, in general, the American Society for Photogrammetry and Remote Sensing (the Imaging and Geospatial Information Society) is a great place to start. Please see: http://www.asprs.org/. Note in particular the career information provided at http://www.asprs.org/career/

Imagery analysis from the salient perspective of a former Central Intelligence Agency officer is provided in the classic article by Dino A. Brugioni, "The Art and Science of Photoreconnaissance," *Scientific American*, March 1996, pp. 78-85.

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An overarching online resource on generic "Remote Sensing" can be found at http://rst.gsfc.nasa.gov/Front/overview.html. This tutorial, which includes quizzes has been regularly updated by the principal author, Dr. Nicolas M. Short, for more than a decade beginning with its inception in 1995.

Among the earliest works to address the fundamental political and security issues associated with commercial satellite imagery are found in *Commercial Observation Satellites and International Security* by Michael Krepon, Peter D. Zimmerman, Leonard Spector, and Mary Umberger, eds., St. Martin's Press, 1990.

An excellent, quite prescient, monograph on the subject can be found in *Secrets for Sale: How Commercial Satellite Imagery Will Change the World*, by Yahya A. Dehqanzada and Ann M. Florini and published by Carnegie Endowment for International Peace, 2000 available at:

http://www.carnegieendowment.org/files/FINALreport.pdf

One of the best compendiums of exemplar studies addressing the benefits and political challenges of commercial satellite imagery can be found in *Commercial Observation Satellites: At the Leading Edge of Global Transparency*, edited by John C. Baker, Kevin M O'Connell, and Ray A. Williamson, A joint publication of RAND Corporation and the American Society of Photogrammetry and Remote Sensing, 2001

Regarding declassified former National Technical Means (NTM) systems see: Kevin C. Ruffner, Editor, CIA Cold War Records, *Corona: America's First Satellite Program*, Center for the Study of Intelligence, 1995; and Dwayne A. Day, John M. Logsdon, and Brian Latell, Editors, *Eye in the Sky, The Story of the Corona Spy Satellites*, Smithsonian history of Aviation Series, ISBN 1-56098-773-1

For other background on imagery analysis and useful training insights for curricula having nuclear nonproliferation applications, the following websites are quite informative:

http://www.globalsecurity.org/intell/library/imint/imint_101.htm

http://www.fas.org/irp/imint/index.html

http://www.defence.gov.au/digo/Imagery_Analysis/imageryQuizT3.htm (Note: This is an Australian Government website that provides a very insightful quiz that is useful for practical training in "context" and "convergence of evidence".)

http://www.eusc.org/html/centre_training_programme.html#IMINT This last link is for a number of imagery analysis training courses. The first includes:

INTERPRETING NUCLEAR INSTALLATIONS USING COMMERCIAL SATELLITE IMAGERY

Course Description: The course focuses on the use of commercial satellite images to monitor the status of nuclear facilities. Starting from the functional description of the Nuclear Fuel Cycle (NFC), this course provides interpretation guidelines of nuclear facilities including: Mining, Milling, Conversion, Enrichment, Fuel Fabrication, Power reactors, Fuel reprocessing, Residues management.

A very informative compendium on the applicability of satellite imagery for arms control and nonproliferation analysis can be found in: "Arms control and non-proliferation: verification by satellite," Recommendation 766, DOCUMENT A/1902, Western European Union Assembly, 15 June 2005 http://www.assembly-weu.org/en/documents/sessions_ordinaires/rpt/2005/1902.html

Finally, for United States citizens interested in pursuing a career in this field, see also:

http://www.nga.mil/portal/site/nga01/index.jsp?epi-content=GENERIC&itemID=8e186150617abf00VgnVCMServer3c02010aRCRD&beanID=1629630080&viewID=Article

Generic Resources for Imagery Analysts

Steven Livingston, "The Journalists' Guide to Remote Sensing Resources on the Internet," Version 2.2, http://www.american.edu/radiowave/earthnews.htm

IWMI RS/GI unit's "Dummies Guide to Search for Satellite Images for a Study Area of Your Interest?"http://www.iwmidsp.org/iwmi/dummies/pdf/Dummies%20Guide%20to%20Search%20for%20Satellite%20Images.pdf (a bit out of date, but still quite useful)

"An Introduction to Satellite Imagery and GIS,"
http://www.npagroup.com/imagery/rs_intro/index.htm

The International Institute for Geo-Information Science and Earth Observation offers a number of generic imagery analysis information and training opportunities http://www.itc.nl/

Remote sensing journals such as journal... http://www.eijournal.com/ and http://www.eomonline.com/, http://www.asprs.org/publications/pers/index.html, and http://www.directionsmag.com/

An overarching online resource on generic "Remote Sensing" can be found at: http://rst.gsfc.nasa.gov/Front/overview.html. This tutorial, which includes quizzes, has been regularly updated by the principal author, Dr. Nicolas M. Short, for more than a decade beginning with its inception in 1995.

http://www.satellitetoday.com/cgi/pub/via/via05010604.html provides a great detailed summary and good explanation of the recent (2006) developments and changes in the commercial imaging satellite industry, and http://www.directionsmag.com

Committee on Earth Observation Satellites, http://idn.ceos.org/

Two online basic educational resources on generic remote sensing aimed at enhancing both US national awareness and global awareness can be found at: and http://www.americaview.org/index.htm, and http://www.globe.gov/r?lang=en&nav=1

"Global Mapper", a "For Fee" database and GIS tool-set http://www.globalmapper.com/

ESRI also has a host of GIS related software and toolsets that are licensable see: http://www.esri.com/index.html

There is also great potential in the future using this site: http://wikimapia.org/

For a "free-lance" imagery analyst for hire, see: http://talent-keyhole.com/

3-D Modeling Resources for Enhanced Visualization

Sketch-Up (by Google), http://sketchup.google.com/

Photosynth (by Microsoft) is a detailed way of preparing texturing drapes for any 3-D models created for enhanced visualization.http://labs.live.com/photosynth/

Canoma (by Metacreations) http://www.canoma.com/ (currently available only through Ebay)

SilverEye (by GeoTango) http://www.geotango.com/ (purchased by Microsoft)

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Joseph W. Cadell, *Deception 101: Primer on Deception*, January 2004. See: http://www.fas.org/irp/eprint/deception.pdf

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Vipin Gupta and Frank Pabian, "Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert: A CTB Verification Exercise Using Commercial Satellite Imagery," *Science and Global Security*, Center for Energy and Environmental Studies, Princeton University, New Jersey, Volume 6, No. 2, 1997. Figures from this paper were broadcast on CNN and published in *NEWSWEEK* after the Indian nuclear tests of May 1998. http://www.milnet.com/pentagon/india/index.htm

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Peter Eisler , "Google Earth helps yet worries government" , *USA Today*, 7 November 2008. http://www.usatoday.com/tech/news/surveillance/2008-11-06-googleearth_N.htm

Finally, to review just how far things have come in the past twenty years and the how this "double-edged sword" issue has been a continuing concern, please see: Roland S. Inlow, "National Security Considerations: Impact on Intelligence Sources and Methods," *Proceedings: Space Imagery and News Gathering for the 1990s: So What?*, Symposium on Foreign Policy and Remote Sensing, The Patterson School of Diplomacy and International Commerce, University of Kentucky, Lexington, Kentucky, USA, February 24-25, 1989. It succinctly addresses what was then an only postulated sub-one meter commercial imaging satellite's potential impact for military operations, foreign relations, crisis control, third-party intelligence, and misinterpretation.

APPENDIX A:
The Process of Acquiring Supplementary Imagery for Analysis

This is a short tutorial on "how-to" acquire supplementary imagery beyond that currently available without cost through GoogleEarth™, or Virtual Earth®, etc. Often times the spatial and temporal resolutions available through those datasets are insufficient for the task. In those cases, a number of steps are required in order to acquire commercial satellite imagery for subsequent independent study and original imagery research and analysis. Those steps are as follows (and in Figure A1):

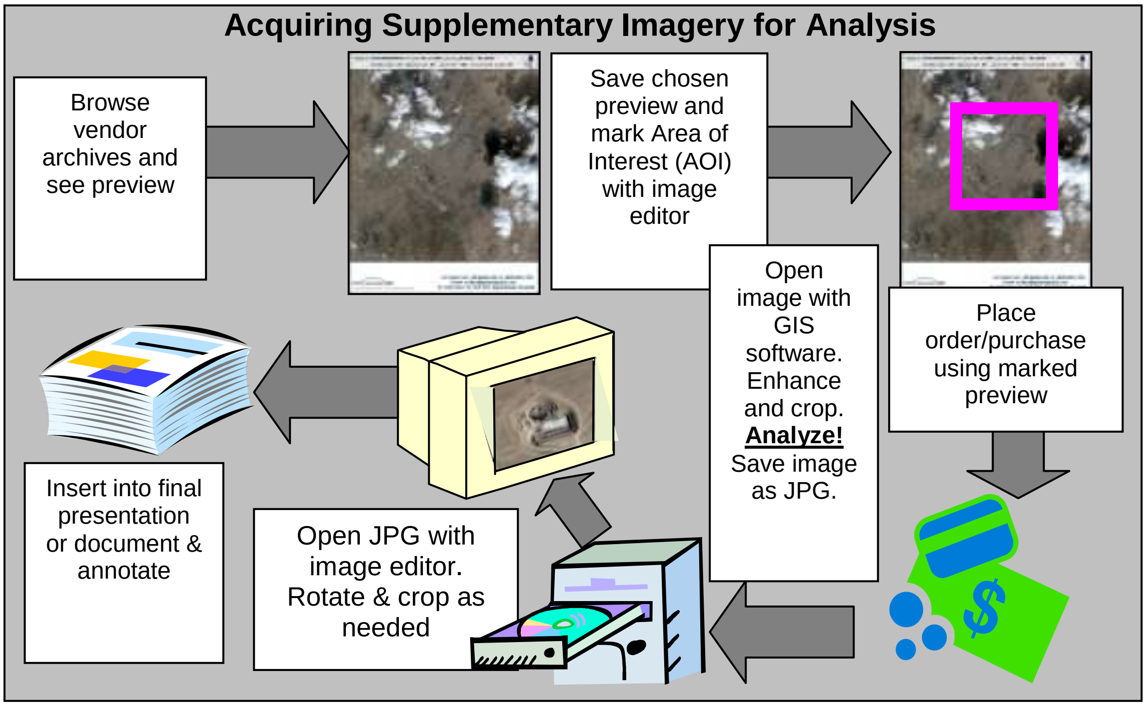

Figure A1: The step-by step process for acquiring supplementary commercial satellite imagery for analysis.

STEP 1: Browse the commercial satellite imagery vendor archives. It is generally easiest to start with GoogleEarth™ and left click (mouse button), on the Digital Globe Coverage "Layers" shown on the lower left hand column of GoogleEarth™ view screen. Double clicking on the "Digital Globe Coverage" line shows a separation by years from 2002 to date. By activating those layers you can learn whether or not there is any coverage available of your area of interest (AOI), and, if it there is imagery available, how recently it was acquired. Alternatively, you can go directly to any of the vendor websites, i.e. for GeoEye's Carterra Online,
http://carterraonline.spaceimaging.com/cgi-bin/Carterra/phtml/login.phtml,
Digital Globe's, http://www.digitalglobe.com/,
or SPOT Image's, http://www.spot.com/html/SICORP/_401_.php.

If a very recent image is required, but not available in any of the archives, any area of the globe can be custom tasked with top priority being assigned to your tasking requirement such that you may have your Area of Interest (AOI) imaged within one to three days if you are willing to pay the maximum premium required by each company.

Please be aware that for some archive browsing you need to register prior to viewing the archives (but not in the case of DigitalGlobe) and that some of these archive tools only work in select internet browsers (i.e., Microsoft Explorer), and not in others.

(NOTE: Often times, it is useful to go back in time in order to determine how old a facility is. This is what is known in the imagery analysis community as determining "negation". Negation is the most recent imagery upon which a facility of interest does not appear hence a date after which the facility was subsequently constructed. This is useful in verifying allegations in which a date of construction is mentioned.)

STEP 2: Selecting an image(s). If the Digital Globe Coverage available through GoogleEarth™ is the chosen method of acquisition, then just left click on the "I" on the date of imagery for a "preview" of the image. If the image is suitable and the area of interest is not cloud covered, then save the chosen preview by "copy" and then "paste" the preview image (full frame) into any image annotation program, such a paint or PowerPoint, and draw a box around the area you are interested in (sub-frame area).

STEP 3: Purchase the Image(s) The minimum available coverage area that must be included in a purchase is usually around 49 square kilometers (i.e., 7 kilometers on a side). The charge for an image is usually $$ per square kilometer. Save the resulting preview image with the marked sub-frame and send it along with the Image ID and the date of acquisition to the vendor for pricing. Orders can be placed either by phone or over the internet. Usually a credit card number is all that is required. You can also purchase whole frames online by just filling in the purchase order forms but this is usually disadvantageous for several reasons, it is far more expensive than ordering sub-frames. Many required parameters are superfluous to meet the needs of most analysts. While most of those can simply be accepted in the default mode, for most nonproliferation visualization purposes it is generally only necessary to specify the "bands" as PAN and MS and **specifically request "PAN-sharpened MS".** Common delivery methods include e-mail, DVD, or directly via the internet using "FTP pulls" if you have, at minimum, DSL internet service. Less critical for simple visualization is the "file type"…usually only GeoTiff or NTIF. Either one is fine, but please be aware that these files are **NOT** standard, in either type or size. They are designed primarily for GIS purposes and are very large, even when the coverage area is the minimum (i.e., hundreds of megabytes) and, as such, they cannot be handled by standard image processing software. Separate purchase of the special software is therefore a necessity as is the requisitely outfitted computer to use that software adequately.

STEP 4: Image Processing and Analysis. Regardless of the method of acquisition, whether by DVD or FTP pull, once you have your commercial satellite image in digital form, you must be able to open it up and view it. This is generally done with a dedicated GIS image processor (i.e., ENVI, http://www.ittvis.com/envi/whatsnew.asp, Carterra Analyst http://www.spaceimaging.com/products/carterra_analyst/index_2.htm, or with GIS "plug-in"s for Adobe Photoshop such as http://www.avenza.com/). Then load the image and display the RGB bands for subsequent enhancement and intermediate cropping. **Use this image for subsequent analysis.** Convert and save the now smaller image into a readily edited format (i.e., TIF or JPG).

STEP 5: Image Editing. Once converted, you may open the image with an image editor (i.e., Adobe Photoshop, http://www.adobe.com/products/photoshop/) for rotation*, final cropping, and any additional color balancing, brightness and contrast adjustments.

STEP 6: Preparation for Publication. Finally, save the resultant image for subsequent imagery analysis and for eventual subsequent insertion into a presentation slide or document with appropriate annotations resulting from that imagery analysis.

Figure A2: "Raw" image as posted on http://www.terraserver.com/samples/samples.asp (a one-meter aerial image from the US Geological Survey)

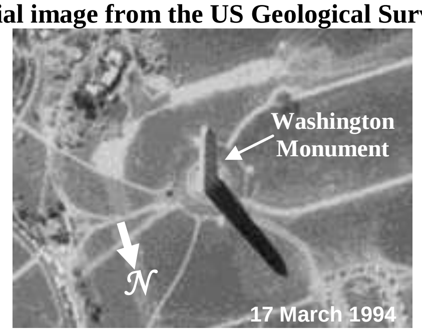

Figure A3: "Value-added" image after rotation and cropping to obtain correct perspective ("obliquity") and have shadows fall towards viewer to enhance visualization along with identifications, date, and north arrow. See http://www.terraserver.com/imagery/image_usgs.asp?cpx=-77.03707928&cpy=38.89071735&usgs_res=13&provider_id=200&t=zoompt

* Rotation is necessary so that objects are ideally viewed in true perspective (also known as correct "obliquity") and/or shadows are cast towards the viewer to help prevent "upside-down" optical illusions. See Figures A2 and A3 below.

APPENDIX B:
Enhanced Visualization with 3-D Modeling

The following are illustrations of the advantages that 3-D modeling provides to both the nuclear nonproliferation professional and dilettante alike. Although the above exemplar study provides a 3-D perspective view of the Kuh-e Barjamali mountain (in which a high resolution commercial satellite image was draped over the available GoogleEarth™ digital elevation model [DEM] terrain), it did not provide an example of how 3-D models of individual buildings and other structures can be useful in establishing overall situational awareness. Such models are critical to any site characterization and can provide greater insight to setting and context in ways that are not otherwise possible with only vertical 2-D overhead images or site plan drawings. As a result, 3-D models are particularly useful for facility pre-inspection planning by anyone considering and/or tasked with onsite inspections. Regardless of the intended application, 3-D models are optimal for visualization purposes and should be utilized wherever appropriate to support facility characterizations and understanding.

The following are two examples where 3-D building models were used to enhance visualization of two different, formerly clandestine Iranian nuclear sites. The first site, Kala (aka Kalaye) Electric (a clandestine gas centrifuge, uranium enrichment, related facility), was initially revealed in February 2003 by the NCRI[1]. Detailed location information was provided such that it was relatively easy to identify on commercial satellite imagery.

> **“**Testing for centrifuge systems is taking place at a location called Ab-Ali. The site is under the cover of a company called Kala (“commodity”) Electric. It has been registered as a watch-making factory. Nevertheless, there are two research workshops next to it. The Ab-Ali site has two large warehouses, 450 meters long, each that are being used as workshops. It has also several administrative buildings. The address in Tehran is “Km 2.5 Ab-Ali highway, next to Kemi Daroo Company. Kala Electric is located in the alley.”

Figure B1 shows how Kalaye Electric is situated on an alley flanked by the pharmaceutical company Chemi Daroo (note that the transliterated spelling is slightly different from that in the above transcript). Figure B2 is a 3-D model of the facility made from the 2-D image in Figure B1 using Canoma modeling software. The model took only about one hour to create. Figure B2 also contains a ground photo of the Kalaye Electric facility as taken in the alley from outside the perimeter security wall to further illustrate the importance of having a “bird’s eye view.”

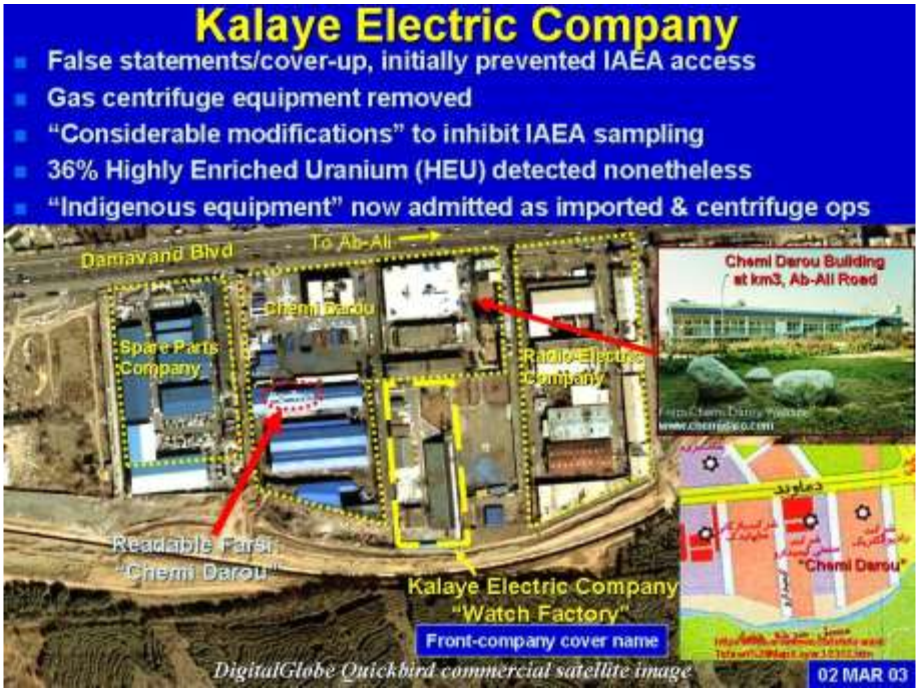

Figure B1: An overview of the Kalaye Electric facility that Iran belatedly admitted had been used to store and test gas centrifuges as part of a clandestine uranium enrichment effort only after the IAEA obtained incriminating evidence of illicit uranium enrichment via onsite sampling. Iran initially told the IAEA that this facility was only an innocuous "Watch Factory". Despite Iran cleansing activities prior to an IAEA onsite inspection and sampling campaign, the IAEA was still able to detect the onsite presence of highly enriched uranium (unnecessary for a peaceful power program). See: http://www.isis-online.org/publications/iran/kalayeelectric.html

Figure B2: An illustration of the utility of 3-D modeling from only a single 2-D commercial satellite image. While not a perfect replication as might otherwise be possible with a Computer Aided Design (CAD) drawing program, such simple modeling helps to better visualize the layout of a site in perspective and clearly exceeds the views possible from the ground as viewed outside a walled compound such as Kalaye Electric.

Among the numerous clandestine facilities that have been disclosed by the NCRI and later confirmed to have a nuclear role (as well as others that were found by the IAEA to be located on "military" sites) is the one facility located in the Tehran neighborhood of Lavizan Shian. No other site better exemplifies the extent to which Iran appears willing to go to prevent detection and verification of its clandestine WMD programs. In May 2003, the NCRI disclosed an alleged biological weapons-related "Technological Research Center" affiliated with Malek Ashtar University and located in Lavizan Shiyan (It should be noted that Malek Ashtar University of Technology is reported to have a campus in Lavizan, and is involved with aerospace applications, explosives, and metal forming)[2]. A search of May and August 2003 commercial satellite imagery led to the discovery of a "facility of interest"…a substantial, secure, engineering-type facility located immediately adjacent to a military, probable aerospace-related, complex located in Lavizan. The facility consisted of three, high-bay, workshop buildings and two multi-story modern laboratory/office buildings, one having a satellite dish on its roof.

Subsequent imagery of early 2004 revealed that this facility had been completely razed, all roads removed, and much of the vegetation cleared (see Figure B3). While such an action was extremely suspicious, given that it occurred at the precise location given in, and subsequent to, the NCRI disclosure…without onsite forensic investigation, the true nature of this former facility could not be unambiguously known. Given the previous failed efforts by the Iranians at both Kalaye-Electric and Lashkar-Ab'ad to hide their work on uranium from IAEA inspectors by the simple removal of equipment and renovation of a facility, the razing of an entire facility would seem to be the next logical, albeit extraordinary, step for Iran to take to inhibit discovery by IAEA environmental sampling.

Figure B3: This figure dramatically shows the extreme lengths that the Iranians appear to be willing to go to prevent the IAEA inspectorate from detecting any evidence of prior fissile material handling onsite. The justification that the Iranians have presented to the IAEA for razing the facility (only months following its exposure by the Iranian dissident group, the NCRI) was to allow for a local park. Subsequent imagery shows that an asphalt soccer field now occupies the location of the three former workshop buildings.

The post-razing image was taken on 10 May 2004 and shows that the clean up had progressed and that essentially all elements of the site have been entirely removed… *most importantly, the top layer of soil has been removed*. Even ancillary structures such as roads, sidewalks, and outdoor stairwells have been removed with little or no trace.[3] When confronted by the IAEA, Iran eventually claimed, "it was a former research and development military site and was used as a physics institute, later for bio-technology research ... for medicine."[4] Iran also insisted that no nuclear materials had ever been onsite and that the facility was only razed to make way for athletic fields (that now include an asphalt soccer field where the high-bay workshop buildings had been) in response to municipal government demands. Nonetheless, in late June 2004, the IAEA was allowed to visit the by-then cleansed site, and IAEA inspectors were allowed to take environmental samples.[5]

From Paragraph 43 of the Board of Governors report, GOV/2004/60, dated 1 September 2004, we find the following:

> "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran" "…According to Iran, A Physics Research Centre had been established at that site in 1989, the purpose of which had been "preparedness to combat and neutralization of casualties due to nuclear attacks and accidents (nuclear defense) and also support and provide scientific advice and services to the Ministry of Defense." "...Iran provided a list of eleven activities conducted at the Centre, but, referring to security concerns, declined to provide a list of the equipment used at the Centre. Iran stated further that "no nuclear material declarable in accordance with the Agency's safeguard [s] was present" and that "no nuclear material and nuclear activities related to fuel cycle were carried out in Lavizan-Shian."[6]

Initially those environmental sampling results were negative.[7] IAEA investigators also sampled two "whole body counters" obtained by Iran for health physics purposes (to detect radiation contamination in humans) that had been located at the Lavizan (in trailers). Again, sampling of those counters and one trailer also produced null results. However, the IAEA also learned that some other dual-use equipment such as "balancing machines, mass spectrometers, magnets, and fluorine handling equipment" that had been procured by the Lavizan-Shian operators. When the IAEA was permitted to sample some of that equipment in early 2006, inspectors found contamination with "small particles of high enriched uranium."[8] According to the IAEA's February 2007 report, the issue of the Lavizan facility, its former nuclear activities, the high enriched uranium contamination, and requested interviews of the senior personnel involved, remain unresolved[9].

Figure B4 is an illustration of how it is possible to create a 3-D model of the former Lavizan facility (textured perspective of model saved as JPEG) and overlay it upon a GoogleEarth™ perspective view in a Powerpoint slide and then save as a combined JPEG image. As in the earlier example, the 3-D model was created using Canoma software and was derived from a single 2-D commercial satellite image.

Figure B4: A 3-D Model of the Lavizan-Shian facility (pre-razing) derived from 11 August 2003 Digital Globe commercial satellite imagery, trimmed and transparently exported with Adobe Photoshop, and overlain on GoogleEarth™ frame capture in Microsoft PowerPoint to enhance site visualization. Note that the only texturing was the satellite image being automatically applied to the building faces with mirror imaging for the other sides

Figure B5 is an illustration of how it is possible to create a 3-D model using Google's newly available software, "SketchUp6", which allows 3-D models to be rendered photo-realistically using ground photographs (obtained from the Internet in this case) that are pasted or "textured" to the sides of the models. Added value using this 3-D modeling method results from the ability to e-mail the resulting model file to anyone in the world (or even directly shared with the entire world via GoogleEarth™) which, once opened, can be viewed in 3-D on the GoogleEarth™ platform from any location on earth in real time.

Note however, that the original ground photos used to make these models were "touched-up" in Adobe Photoshop, as necessary, according to the SketchUp6 user's manual to eliminate any overlying objects (i.e. power poles) from foregrounds. Some building models were also created from pieces of building images where complete side views were just not available (as a result, such models are to be considered as only close approximations to reality and to be used only for visualization and site familiarization purposes). Such "doctoring" was earlier described with regard to original satellite image data as anathema. However, in the case of model creation, as long as no non-existent additional features are created, such rendering refinements are just part of the process. According to the Google description for SketchUp, they are entirely permissible, so long as the viewer is fully informed of all such alterations

Figure B5: This is a very simple 3-D Model (KMZ file created with Google's cost-free SketchUp6 software) of a portion of the Natanz uranium enrichment facility as viewed in GoogleEarth™. Such models can be posted directly on to the GoogleEarth™ platform or e-mailed to anyone on earth, which once opened in GoogleEarth™, allow 3-D viewing from all sides and angles for walk-arounds and fly-arounds of the model in real time. (Textures are stylized with Adobe Photoshop and were derived from ground photos of the buildings found on the internet).

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Table A: Minimum Overhead Imagery Resolution (in meters) Necessary for Analysis of Nuclear Fuel Cycle Related Facilities

Facility of Interest	Detection	General Facility Identification & Site Layout	General Functional Building Description	Precise Building Identification	Technical Analysis & OMV
Uranium mining, processing & feed materials	5 to 10	1 to 5	1	0.2 to 0.5	.5 for mines and processing, limited other
EMIS Enrichment Facilities	2 to 5	1 to 3	1	0.2 to 0.5	Limited to none at any resolution
Gas Centrifuge Facilities	N/A	1 to 3	0.5	0.2	Limited to none at any resolution
Heavy Water Plants	5	1-3	0.5	0.2	0.2
Research Reactors	2 to 5	1 to 3	1	0.5	Limited to none at any resolution
Plutonium Production Reactors	2 to 10	1 to 5	1	0.5 to 1	0.5 to 1
Nuclear Weapons R&D (i.e., High Explosives Testing)	1 to 2	0.5 to 1	0.5	0.5	0.1 to 0.5
Nuclear Weapons Mfg.	1 to 2	1	0.5	.1 to .5	Limited to none at any resolution
Test Site	10	1 to 3	1 to 2	.5 to 1	0.5 to 1

Table: Adapted from, Anne Florini, "The Opening Skies: Third-Party Imaging Satellites and US Security," *International Security*, Vol. 13, No. 2 (Fall 1988), p. 98; and G.T. Richardson and Robert N. Mertz, "High Resolution Commercial Imagery and Open Source Information: Implications for Arms Control," *Intelligence Note*, ACDA (May 1996), p.4.

Detection: Identify the location of a facility of activity of FMCT/NPT interest (locate and define outline of nuclear related facility in light of other descriptive or geographically specific information) (Note: It can often be possible to detect and identify characteristic features, such as security fencing or power lines, despite the fact that any given section of such fencing may be of sub-pixel size, or below the given resolution of the image, because they are generally linear and span many pixels.)

General ID: Determination of general facility or activity type (Discriminate between research lab, mfg. facility, explosives prod, storage site)

General Functional Building Description: Size/dimension, configuration/layout of buildings (i.e., laboratory, production, utilities, support)

Precise Building ID: Precise determination of building function (i.e., reactor type/size, propellant mixing/casting, machine shop, administration)

Table B: Comparison of the Various Types of Commercial Imaging Systems and Their Relative Utility

Imagery Type	*Advantages*	*Disadvantages*
Optical/Electro-Optical: the visual spectrum in Panchromatic (B&W) and non-visual near-infrared bands	Very high resolution possible. Near-infrared is optimal because it can penetrate haze and can be merged with true color for more natural appearance as an aid to interpretation.	Acquisition restricted by cloud cover and limited to daylight hours.
Multi-spectral: (Incl. Hyper-spectral)* Includes both visual bands and non-visual bands	Provide the means to view sites in a more natural, true color setting. May also provide a means for determining material/chemical composition and material transfer, and for detecting camouflage and concealment activities	Slightly lower resolution (i.e., currently 2.5-meters).
Thermal infrared:	Provides a quantifiable measure of heat transfer as a basis for determining site status such as reactor power operations. When correlated with optical could determine heat flow, both qualitatively and quantitatively, from waste ponds, steam lines, vents, stacks, cooling towers, etc.	Generally of too low resolution for anything other than facility activity monitoring (currently no better than about 20 to 90 meters)#.
Radar:	Provides 24-hour monitoring capability, can penetrate clouds, and useful complement to optical imagery.**	Resolution no better than 6 meters at present. Processing and interpretation of imagery is much more difficult.

* Irmgard Niemeyer, Satellite Imagery Analysis for Safeguards and Non-Proliferation, *Strengthening detection capability for safeguards*, Institute of Nuclear Materials Management (INMM), Changing The Safeguards Culture: Broader Perspectives And Challenges, Santa Fe, New Mexico, USA, October 30 – November 2, 2005 http://www.inmm.org/topics/contents/wgreport.htm#2; Christopher L. Stork, Heidi A. Smartt, Dianna S. Blair, and Jody L. Smith, "Systematic Evaluation of Satellite Remote Sensing for Identifying Uranium Mines and Mills," Sandia National Laboratories, January 2006 http://www.prod.sandia.gov/cgi-bin/techlib/access-control.pl/2005/057791.pdf; and Q. S. Bob Truong, "Road Map B&W and Colour Imagery," Strengthening detection capability for safeguards, Institute of Nuclear Materials Management (INMM), Changing The Safeguards Culture: Broader Perspectives And Challenges, Santa Fe, New Mexico, USA, October 30 – November 2, 2005, http://www.inmm.org/topics/contents/wgreport.htm#2

See Multispectral Thermal Imager (MTI) http://www.fas.org/spp/military/program/masint/mti.htm and http://directory.eoportal.org/pres_MTIMultispectralThermalImager.html and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), http://asterweb.jpl.nasa.gov/ and http://edcdaac.usgs.gov/aster/asteroverview.asp

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