

The background of the slide is a high-resolution satellite image of Earth from space. The image shows a vast expanse of blue oceans and white clouds. A bright sun is visible in the upper right quadrant, creating a lens flare effect. The horizon of the Earth is visible as a curved line across the middle of the frame.

High Resolution Commercial Satellite Imagery as a Nonproliferation Tool

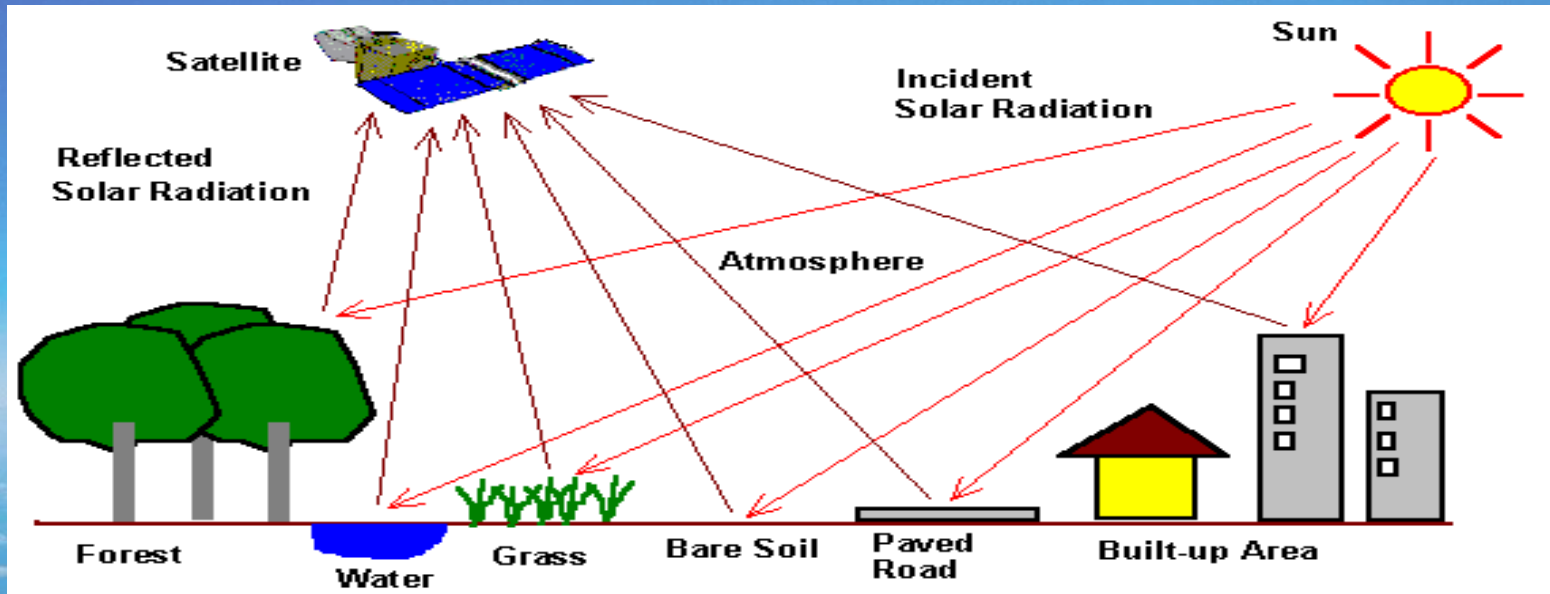
Overview

Satellite Imagery – The Basics

Why and How ISIS Uses Imagery

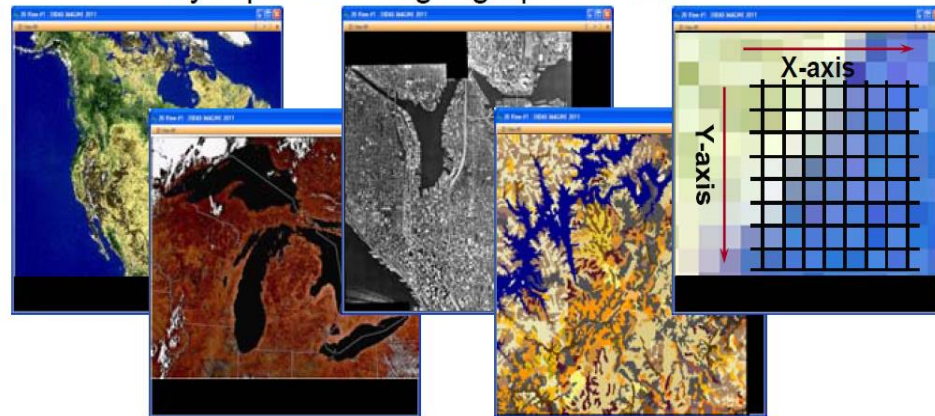
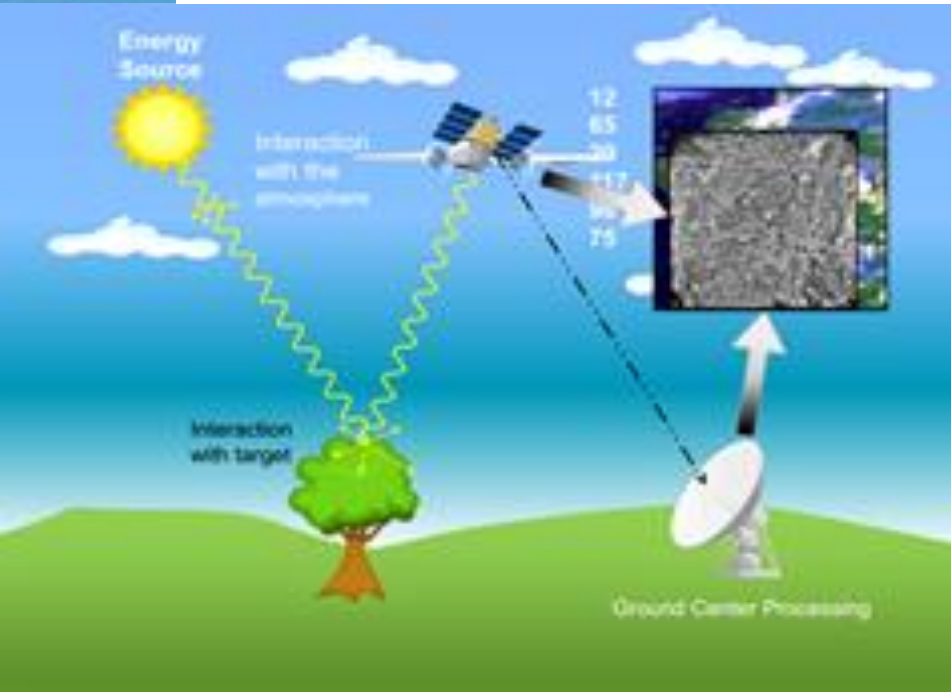
Examples

What is a Satellite Image?



Data that are organized in a grid of columns and rows

Usually represents a geographical area



Up to the late 90s: acquisition and use only for national governments (that kept their capabilities and knowledge classified and under extremely tight security controls).

GIS (Geographic Information System) data is now:

Free

Purchasable

The logo for Google Earth, featuring the text "Google™ earth" in a white, serif font against a black background with a view of the Earth's horizon from space.The logo for DigitalGlobe, consisting of the text "DIGITALGLOBE" in a blue, sans-serif font with a blue arc above the letters "I" and "O".The logo for GeoEye, featuring a stylized globe icon followed by the text "GeoEye" in a green, sans-serif font.The logo for Airbus Defence & Space, featuring the text "Astrium is now" in white, followed by the Airbus logo (a circle with a dot) and the text "AIRBUS DEFENCE & SPACE" in white, sans-serif font.

Satellite Imagery: From Corona (KH-4) to Commercial Comparison

**US "Spy" Photo
(Declassified in 1995)**



Corona Photo, 25 September 1967

Source: <http://www.nro.gov/corona/cor-ab.html>
http://en.wikipedia.org/wiki/File:Corona_pentagon.jpg

Google Earth Image



**Google Earth 25 October 2007
(Digital Globe)**

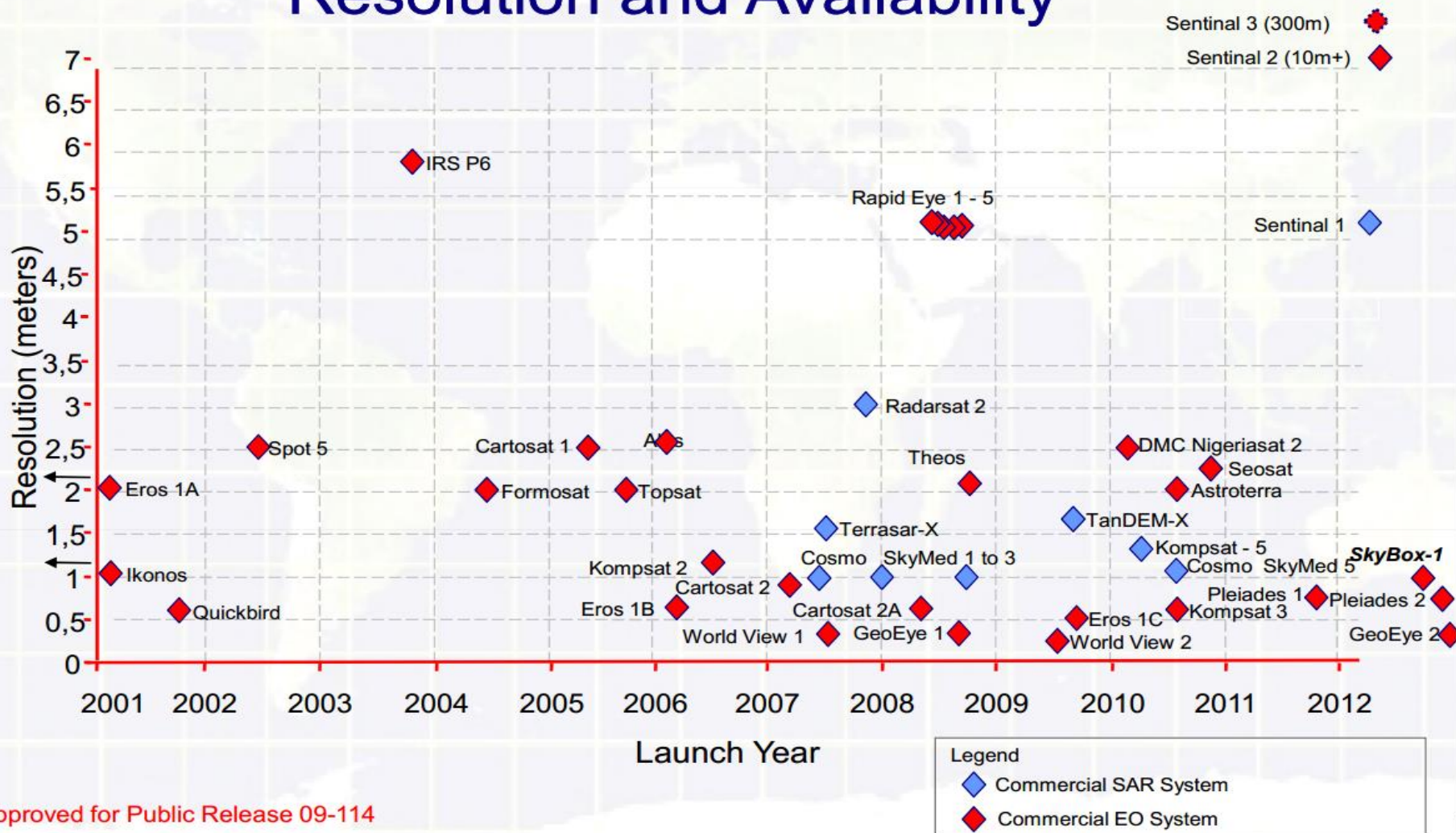
➤ **Purchasable** through commercial vendors

- Panchromatic
- Multispectral
- Hyperspectral
- Infrared

Remember: Commercial = 0.5 meters resolution

Any lower resolution is resampled to 0.5 m for sale to commercial customers

Satellite Sensors: Resolution and Availability



Approved for Public Release 09-114

<https://www1.nga.mil/About/WorkingWithUs/CooperativeAgreements/Documents/TOPS%2017%20Feb%20industry%20Day%20final%20Briefed%20Public.ppt>

Commercial satellite imagery has a wide range of uses at the IAEA and in other entities that are part of arms control treaty regimes.

Satellite Imagery Analysis

A Growing Role in State Infrastructure Analysis in the IAEA Safeguards Division

Satellite Imagery Analysis and GIS Support to International Safeguards



- Monitor NFC sites and activities
- Verify States' declarations
- Support inspection activities
- Investigate possible undeclared activities
- Conduct GIS analysis and generate geospatial products
- Employ emerging methods of geospatial technology

Create and Update Site Plans

- Compile multi-temporal imagery
- Assess changes feature by feature
- Attribute features
- Generate GIS-based map/illustration
- Internal standardized geodatabase schema
- ArcServer (SDE) vector technology
- Expose data through web services



Geospatial Products

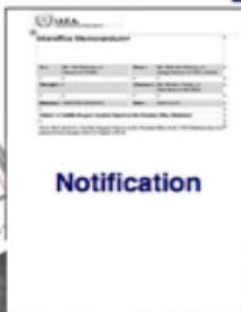
Verification Report



Baseline/Update Report



Notification



Brief Report

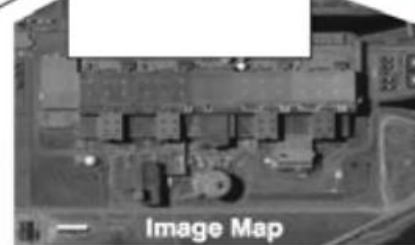
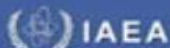


Image Map

3D Modeling



12th Annual UNGIWS Plenary March 28-30 2012

<http://ungiwg.cibto.org/meetings/12th-ungiwg-plenary-2012/>



12th Annual UNGIWS Plenary March 28-30 2012



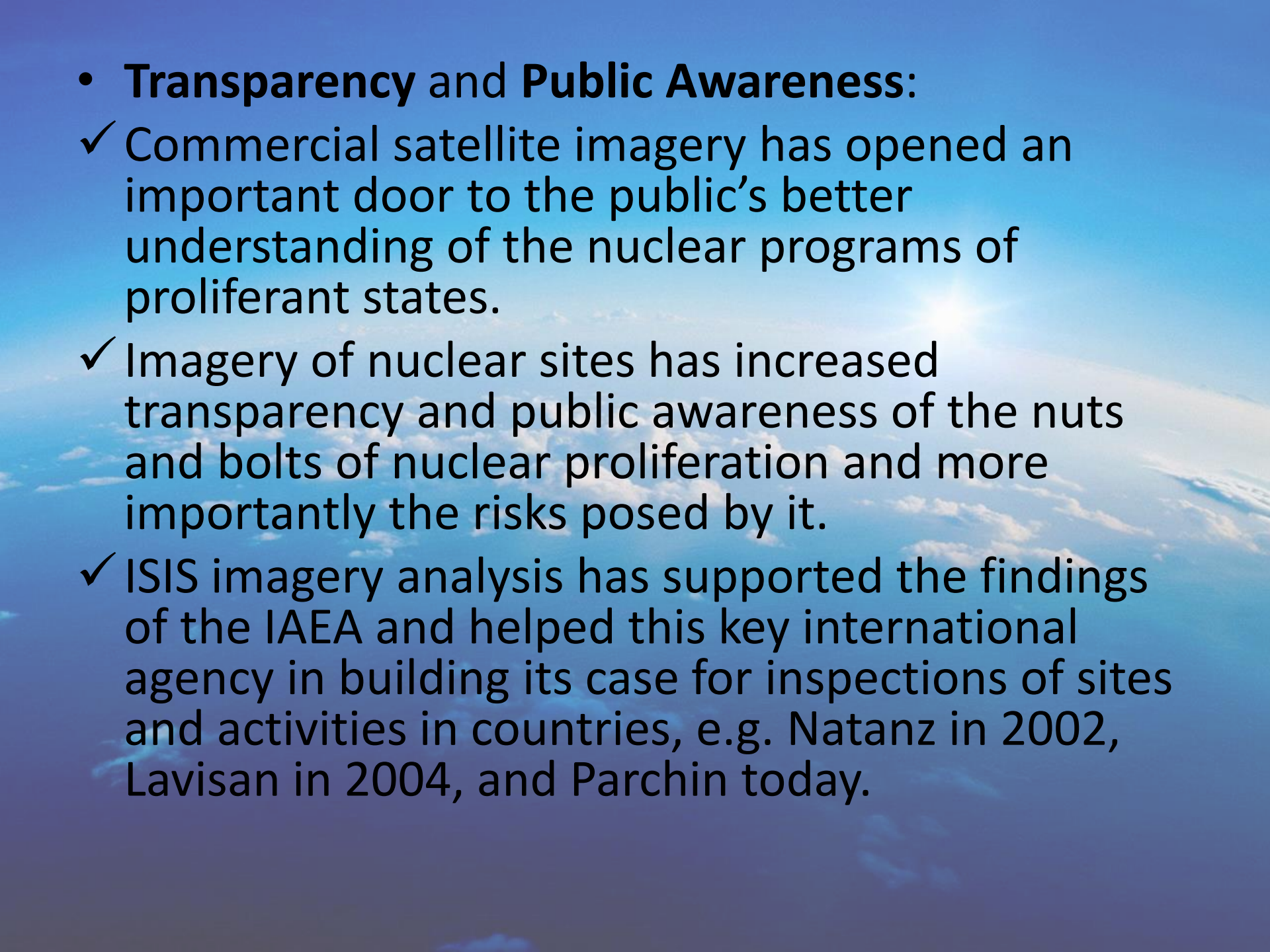
Nuclear Nonproliferation, Safeguards, and Security in the 21st Century

History of ISIS's Use of Imagery

- ISIS started working regularly with commercial satellite imagery in the late 1990's.
- Our first significant case involved the 1998 Pakistani nuclear test. Since then we have regularly published imagery studies of nuclear programs in up to a dozen states (Iran, North Korea, Syria, India, and Pakistan).
- We produce a relatively simple product for public dissemination.
- ISIS products have received extensive media coverage over the years.

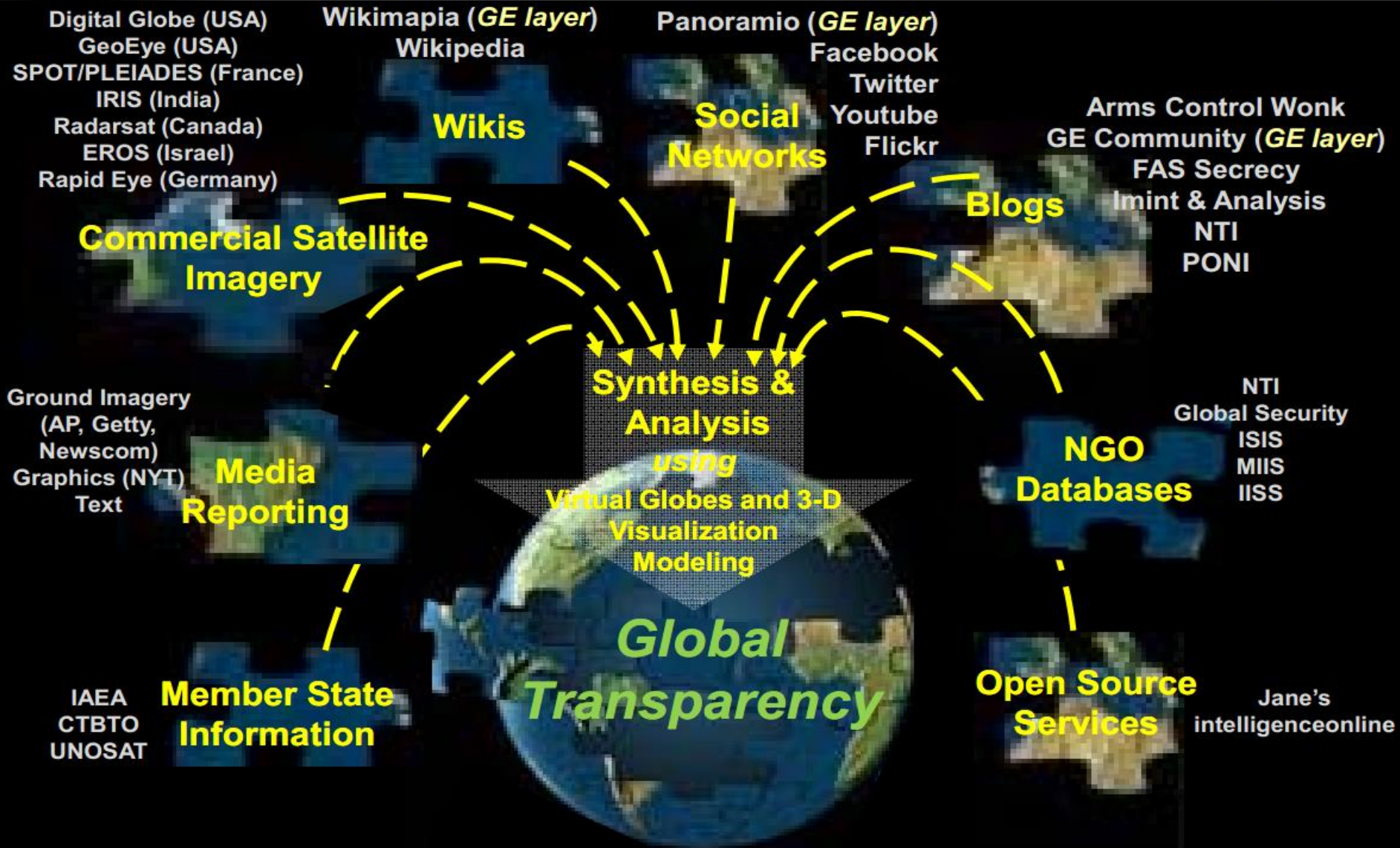
Why ISIS Uses Satellite Imagery

- The use of satellite imagery is an important component of the research and educational mission of ISIS and other NGOs because it's a powerful **tool** for:
 1. **Public and Governmental Education**
 2. **Public Awareness**
 3. **Transparency**
 4. **Better Analysis of Nuclear Weapons Capabilities**
 - Can prove or disprove **media claims**;
 - Increases our ability to hold governments **accountable**.

- 
- **Transparency and Public Awareness:**
 - ✓ Commercial satellite imagery has opened an important door to the public's better understanding of the nuclear programs of proliferant states.
 - ✓ Imagery of nuclear sites has increased transparency and public awareness of the nuts and bolts of nuclear proliferation and more importantly the risks posed by it.
 - ✓ ISIS imagery analysis has supported the findings of the IAEA and helped this key international agency in building its case for inspections of sites and activities in countries, e.g. Natanz in 2002, Lavisan in 2004, and Parchin today.

- Tool for **Better Analysis** of Nuclear Weapons Capabilities:
 - ✓ Commercial satellite imagery can publicly reveal sites that increase a proliferant state's capability to make plutonium or highly enriched uranium for nuclear weapons.
 - ✓ Commercial satellite imagery allows for better empirical estimates of proliferant state current and projected inventories to make fissile material for nuclear weapons.

Using the New Geospatial Tools: Putting All the Pieces Together



Open Source "Crowdsourcing" + Geospatial Tools = Global Transparency

* Exemplars are NOT meant to be viewed as exhaustive

Frank V. Pabian, *Strengthened IAEA Safeguards-Imagery Analysis: Geospatial Tools for Nonproliferation Analysis*, Los Alamos National Laboratory, June 22, 2012.

Successful Use of Imagery?

- Purchasing the Satellite Image alone is NOT enough!

In order to extract information you need

two more steps

1. Image Processing and Manipulation

Software: ERDAS Imagine, ENVI

Bands: 3 Multi, 1 NIR, 1 Pan

Breakpoints

Look Angles

Software Options

ERDAS Imagine

Professional: \$5250

(+ \$948/yr maintenance)

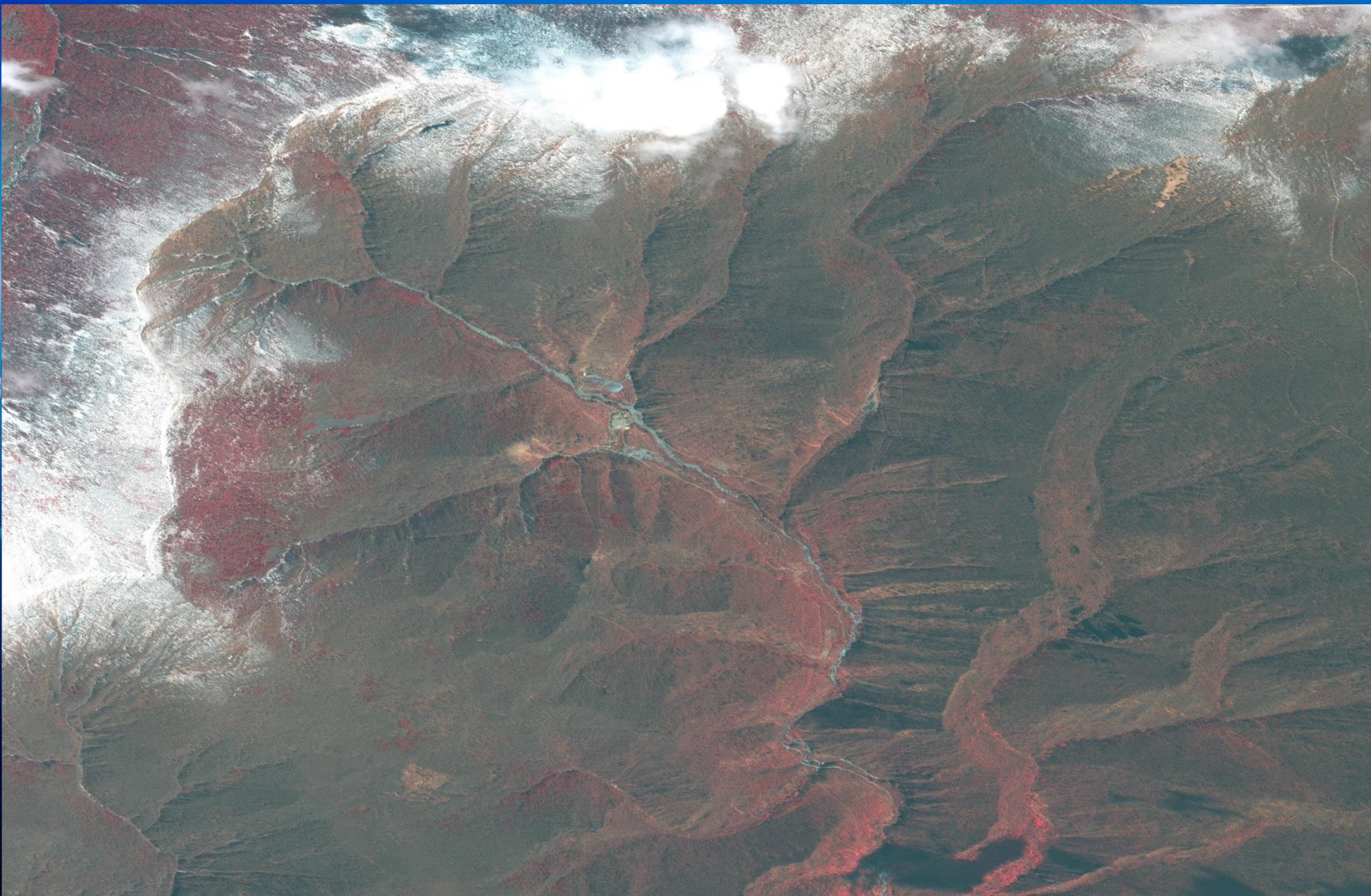
ENVI

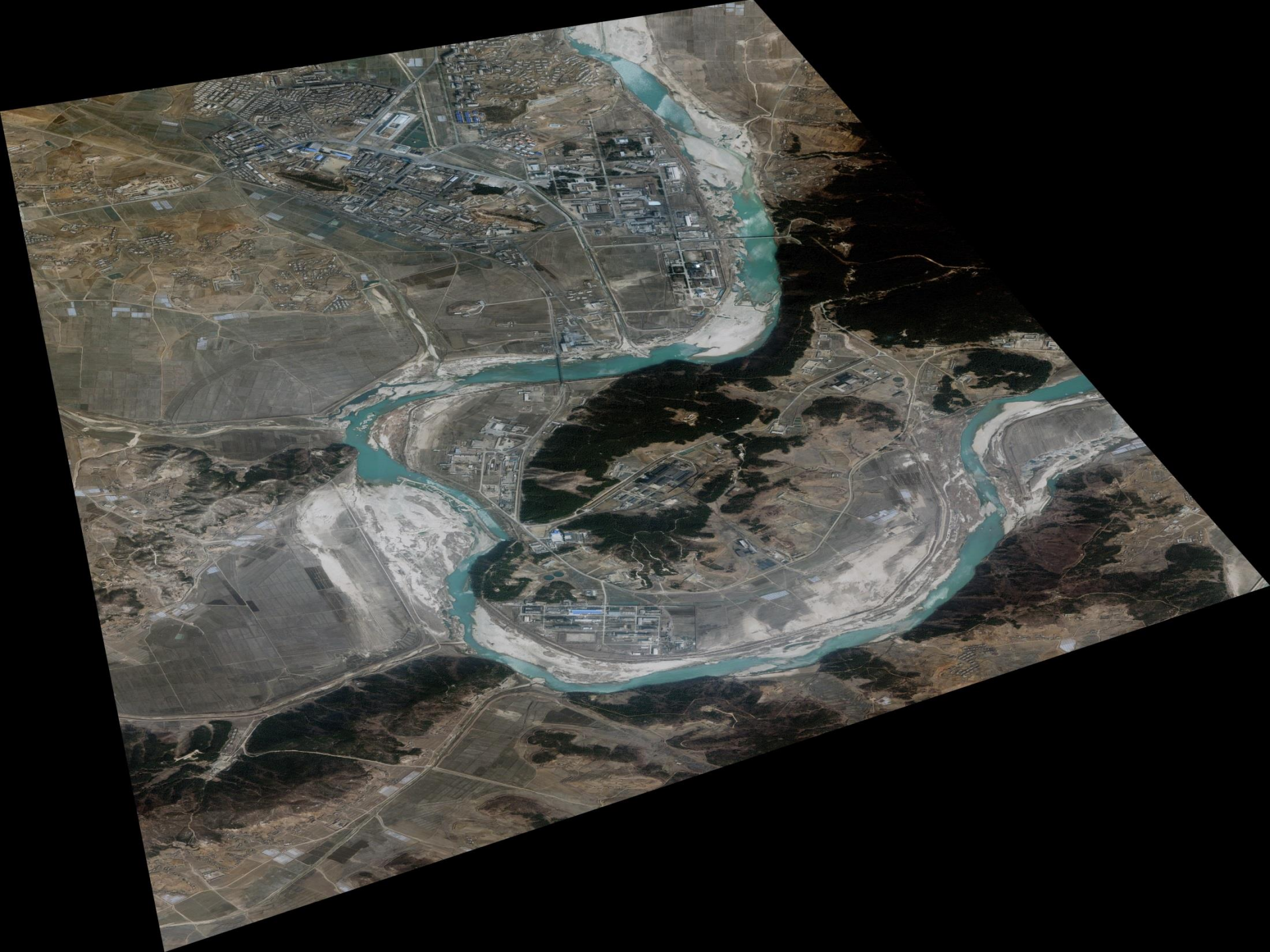
ENVI Node-locked: \$6,305

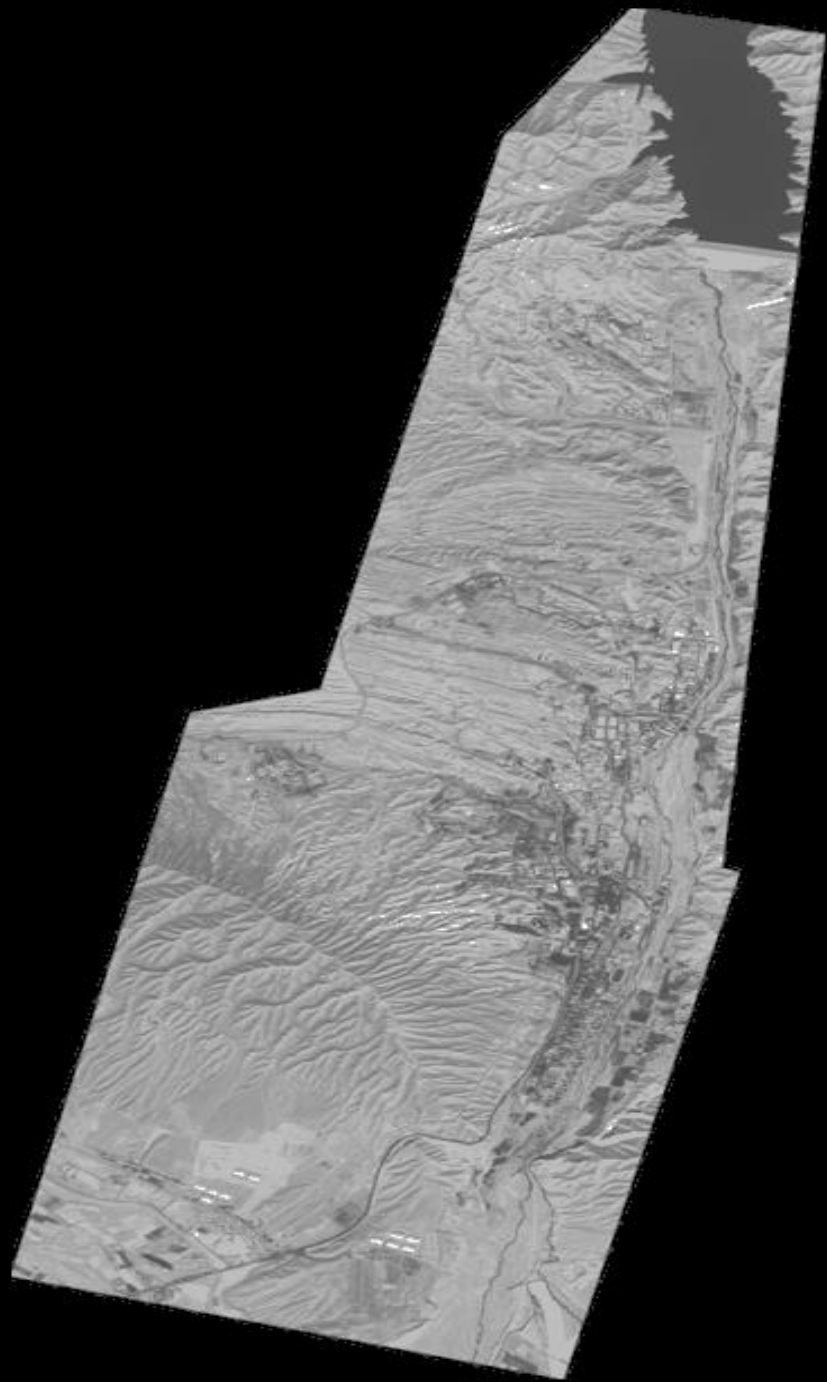
(+ maintenance)

Advantage: \$2500 (+ \$456
per year for maintenance)

Raw Image

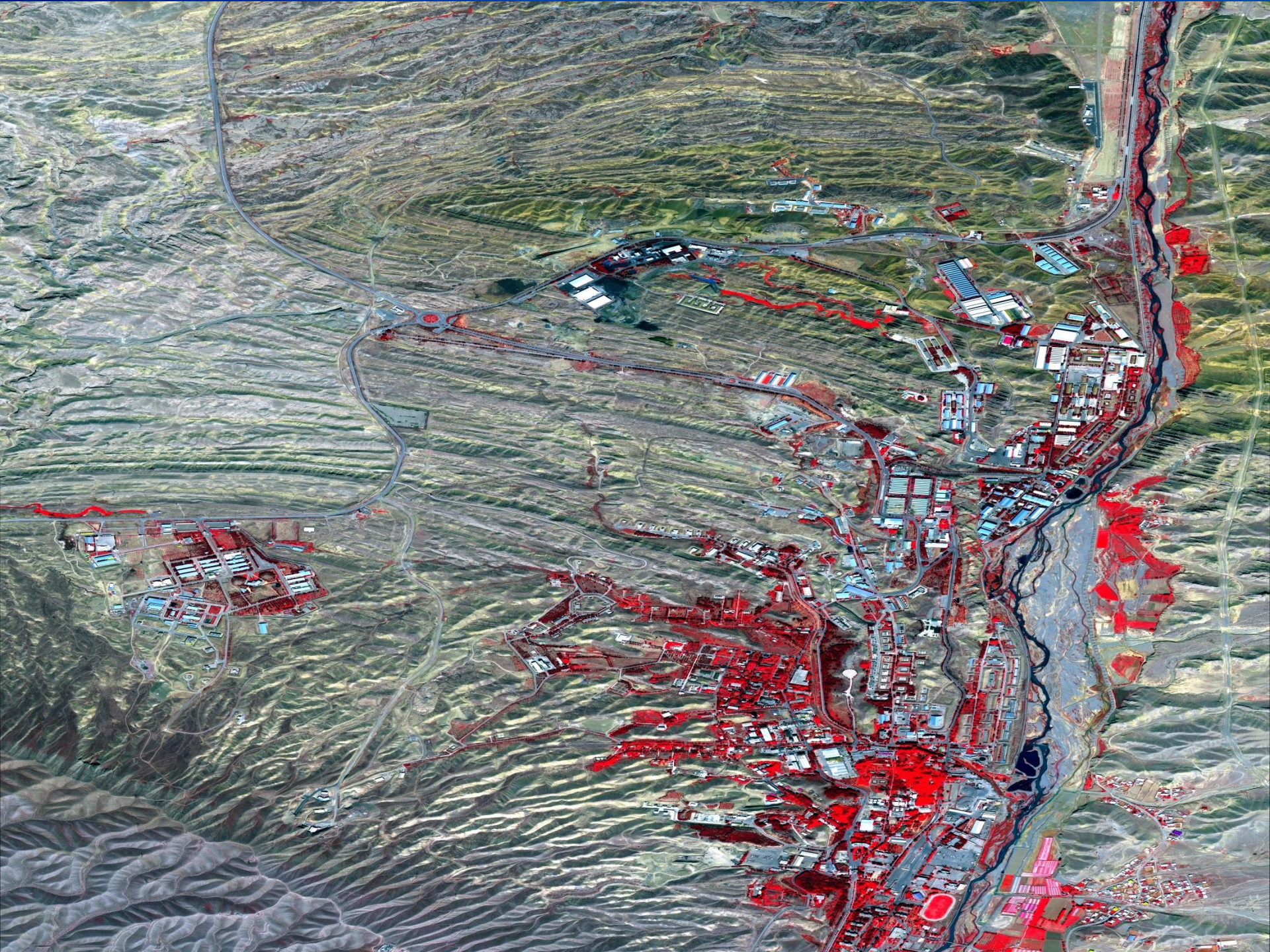






An aerial view of Earth from space, showing a bright sun in the upper right corner. The Earth's surface is covered in blue oceans and white clouds. The text "Processing and Manipulations Gives You..." is centered in the image.

**Processing and Manipulations
Gives You...**



2. Imagery Analysis

- Commercial satellite imagery, by itself, is nothing more than a compendium of “**Raw Data**” in the form of pixels. This is of little use without the addition of “**Interpretation**” and “**Analysis**”.
- Imagery analysis is the process of deriving labels and determining their significance, both of which add value to the raw data. Usually, you can find a nuclear site using one of two strategies:
 - **1) Direct Recognition:** identifying a nuclear reactor through one of its signatures (ex: cooling system)
 - **2) Inference:** from elements such as security fence, size and shape of buildings, location, differential vegetation etc.

Example of Direct Recognition

Chashma, Pakistan, December 14, 2013



Heavy Water Towers

Arak, Iran



- Imagery interpretation can also be described as enlisting the basic “Five S’s”
 1. **Size:** awareness of the scale of the imagery (for TRUE sizes)
 2. **Shape:** Physical characteristics of the objects
 3. **Shadows:** careful of sun angle!
 4. **Shade:** the tonal brightness and contrast
 5. **Surrounding Objects:** context

But that's NOT all!

- **Signatures:** cooling towers, long rectangular buildings, domes, Water ponds, large ventilation systems such as vent stacks, large electrical switchyards, security perimeters etc.
- **Time:** temporal changes determined from monitoring a site with multiple images taken at different times.

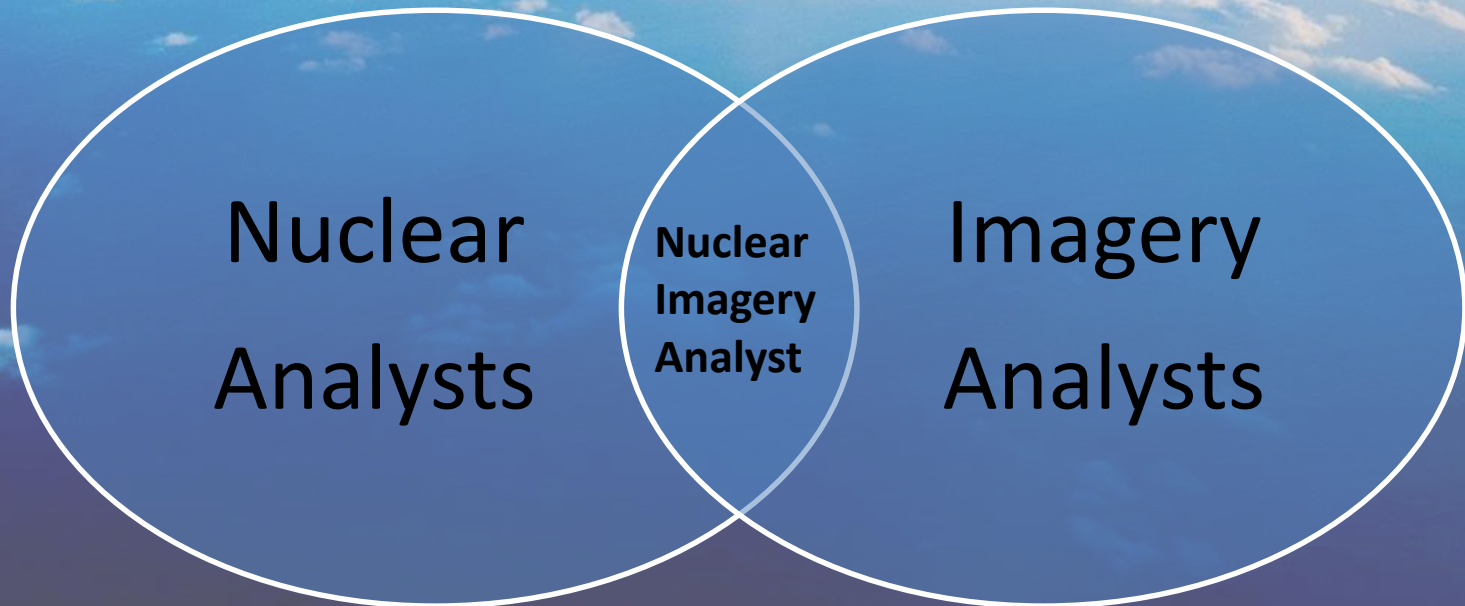
Fuel Cycle Activities and their Observable Signatures

Uranium Mining and Milling	Piles of ore and tailings, large ore trucks	High
Conversion	No signatures different from chemical plant	Low
Gas Centrifuge	Low requirements for electricity and water	None
Gaseous Diffusion	High power demand, high voltage supply lines, switch yards, cooling towers, heat generation	Medium
EMIS	High power demand, local transformers	Low
Fuel Fabrication	No observables	None
Reactors	Containment buildings, power lines, cooling towers	Low
Reprocessing	Road or rail access, high capacity water supply, water treatment, transport canisters	Medium

Analysis

The use of Imagery for Nonproliferation purposes strongly relies on

Imagery Expertise + Nuclear Expertise



Government

Acquires Imagery

Analysis by General
Imagery Analysts

Seek Nuclear
Experts if Needed

ISIS

Acquires Imagery

Analysis by Nuclear
Experts

Seeks General
Imagery Analysts if
Needed

What ISIS Can Bring to the Table

Imagery Analysis needs to be **integrated** with other information:

General Nuclear Fuel Cycle Knowledge

State Specific Nuclear Fuel Cycle Knowledge

History of Each Nation's Nuclear Program

Each Nation's Nuclear Trading Schemes

Illicit Nuclear Procurements



**Analysis is Very Important
because...**

**...you have to be careful of
Imagery**

Imagery Analysis: Shadows & Setting Exemplar

What is this?
(Without shadows,
fairly easy)



What is this?
(Without shadows,
fairly difficult)



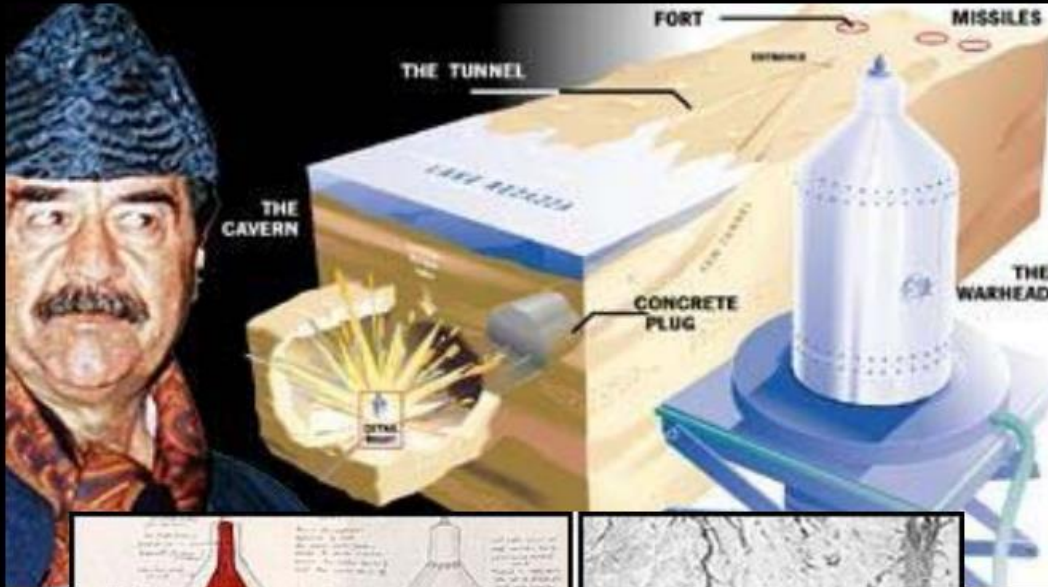
Image © 2008 Sanborn

© 2008 Tele Atlas

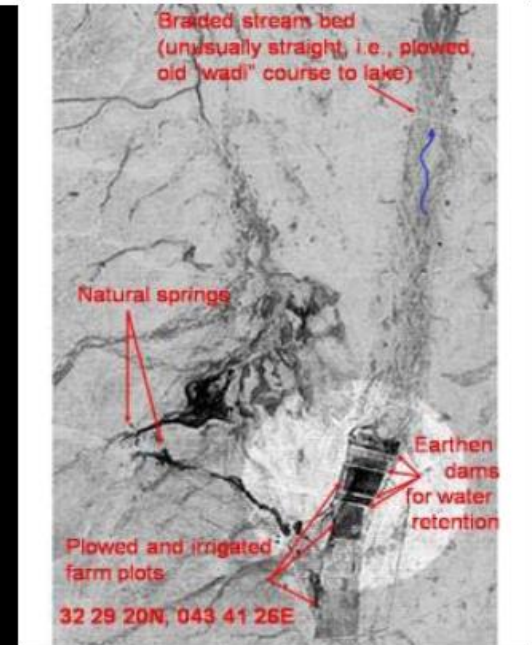
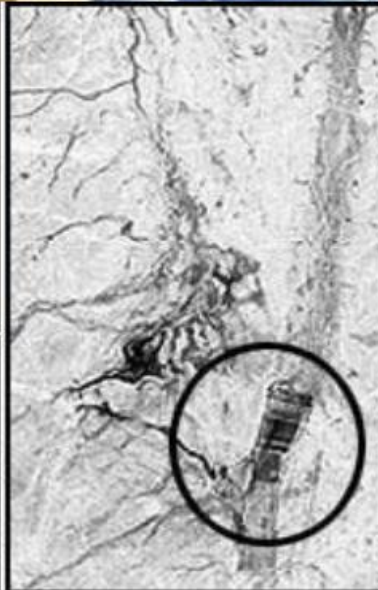
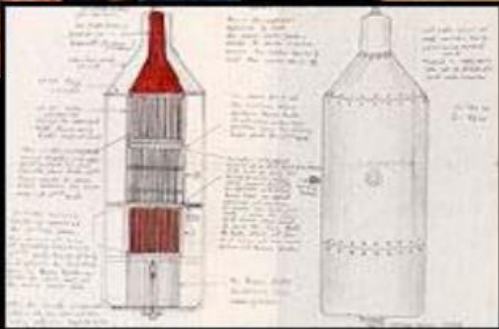
© 2008 Tele Atlas

<https://www1.nra.mil/kids/aeoint/imagery/Pages/Shadow.aspx>

Mistakes Do Happen



Alleged Iraqi nuclear test site was claimed to have been located, but the site is nothing but a dry wadi that was cross-diked for water retention in plowed farm plots using water from adjacent springs



<http://www.globalsecurity.org/wmd/library/news/iraq/2001/stirevnws01015.htm>

Can You Find the Syrian Reactor?



Answer: Lower left is the al Kibar Covert Plutonium Production Capable Reactor disguised to look like a Byzantine fortress (two such fortresses are in the vicinity of al Kibar: Halabiyah and Zalabiye)
The other three images are of an exemplar Byzantine fortress (Zippori National Park, Israel)

Beware of Imagery Data Manipulation (aka: "Fauxtography") as It Can Lead to Erroneous Conclusions!

Comparison slide as taken directly from IAEA Inspector Dr. Abushady's briefing on Egyptian National Television that claimed to be "To Scale," and therefore "Proved" that the Al Kibar facility was not comparable to the reactor at Yongbyon



Reactor Image Comparison that is "TO SCALE"

(Left image re-scaled to match right image vertically and horizontally)

(Compare with Dr. Abushady's slide)

The reactor hall building at Yongbyon is a little more than twice as tall as the Al Kibar Building (~45 meters versus ~20 meters high as measured from ground level), BUT at Al Kibar the reactor was entirely below grade (vice above ground at Yongbyon) and likely had a basement depth of at least 16 meters*, providing a total height of at least 36 meters or no more than 9 meters less than the Yongbyon reactor hall. This comparison shows that all the dimensions of Al Kibar are slightly less than, but nonetheless still proportional to, those of the Yongbyon reactor hall.



•Source: ODNI images and <http://www.armscontrolwonk.com/2149/iaea-official-on-the-box>

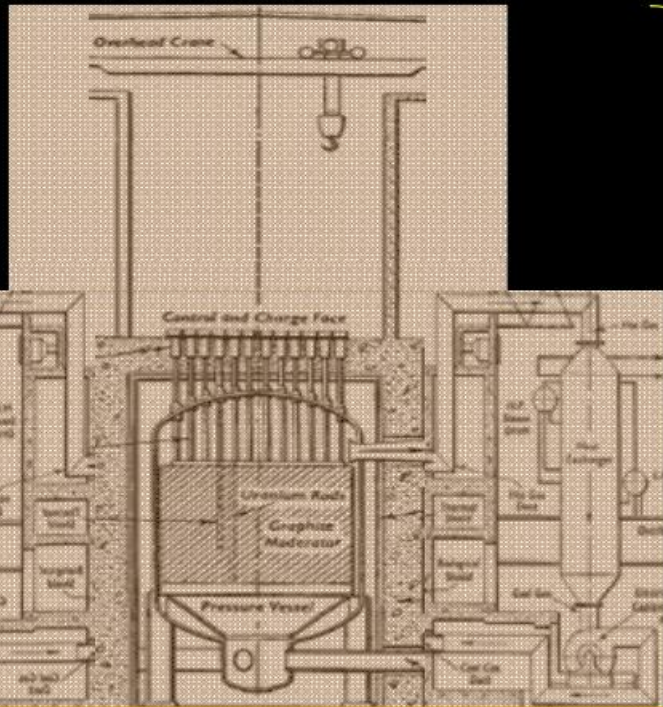


Generalized Reactor Schematic Comparison to Illustrate Basis for Outward Dissimilarities

- 1) Yongbyon reactor above ground
- 2) Al Kibar Reactor below ground

Yongbyon, DPRK

32 METERS wide (reactor hall)

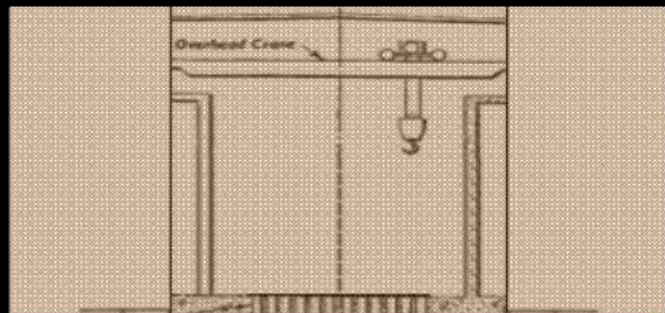


~45 meters tall

Al Kibar, Syria

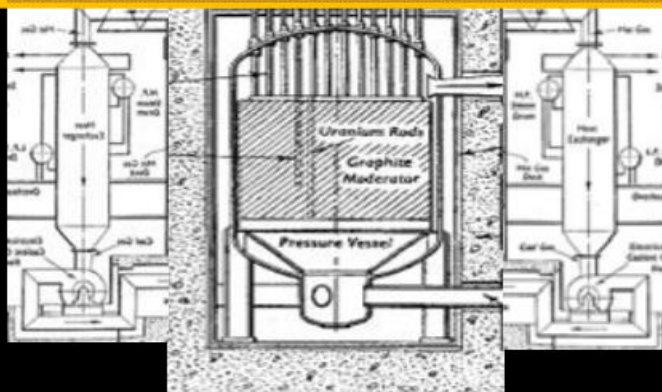
45 METERS wide (outer façade)

22 METERS wide (inner reactor hall)



~20 meters tall

Ground Level



Adapted from: <http://solar-photon.com/images/CalderA.pdf>

Original Image Un-“Photoshopped”



<http://thelede.blogs.nytimes.com/2008/07/10/in-an-iranian-image-a->

July 2008 Iranian missile launch was “Photoshopped”



<http://thelede.blogs.nytimes.com/2008/07/10/in-an-iranian-image-a->

Why Stop at Just Four?



<http://www.armscontrolwonk.com/1955/missile-palooza>



ISIS Imagery Examples



PARCHIN, IRAN

Parchin: Before and After



Parchin February 4, 2013



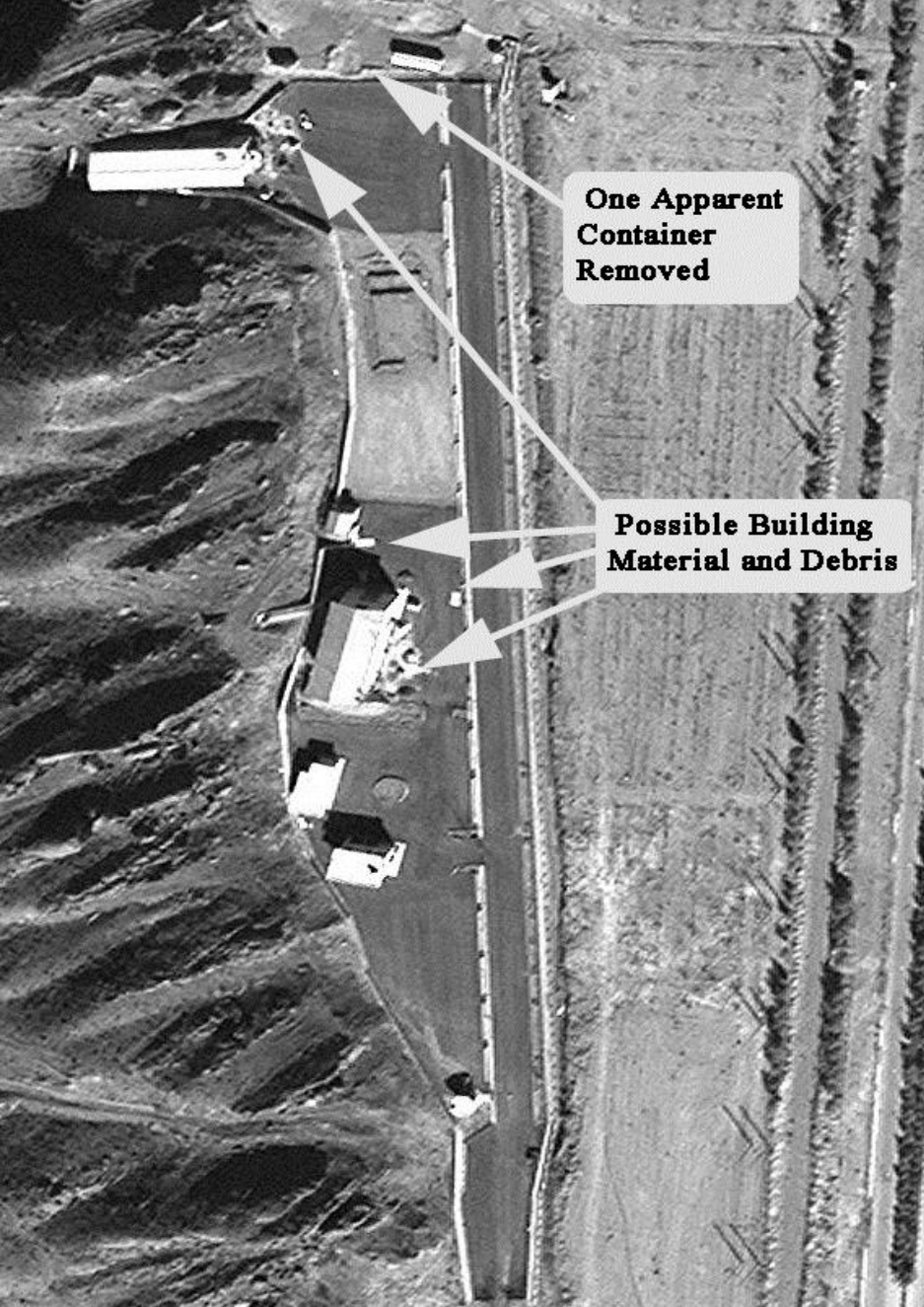


Image Credit: Digital Globe-ISIS
Image Date: January 30, 2014
Not for use without Digital Globe licensing

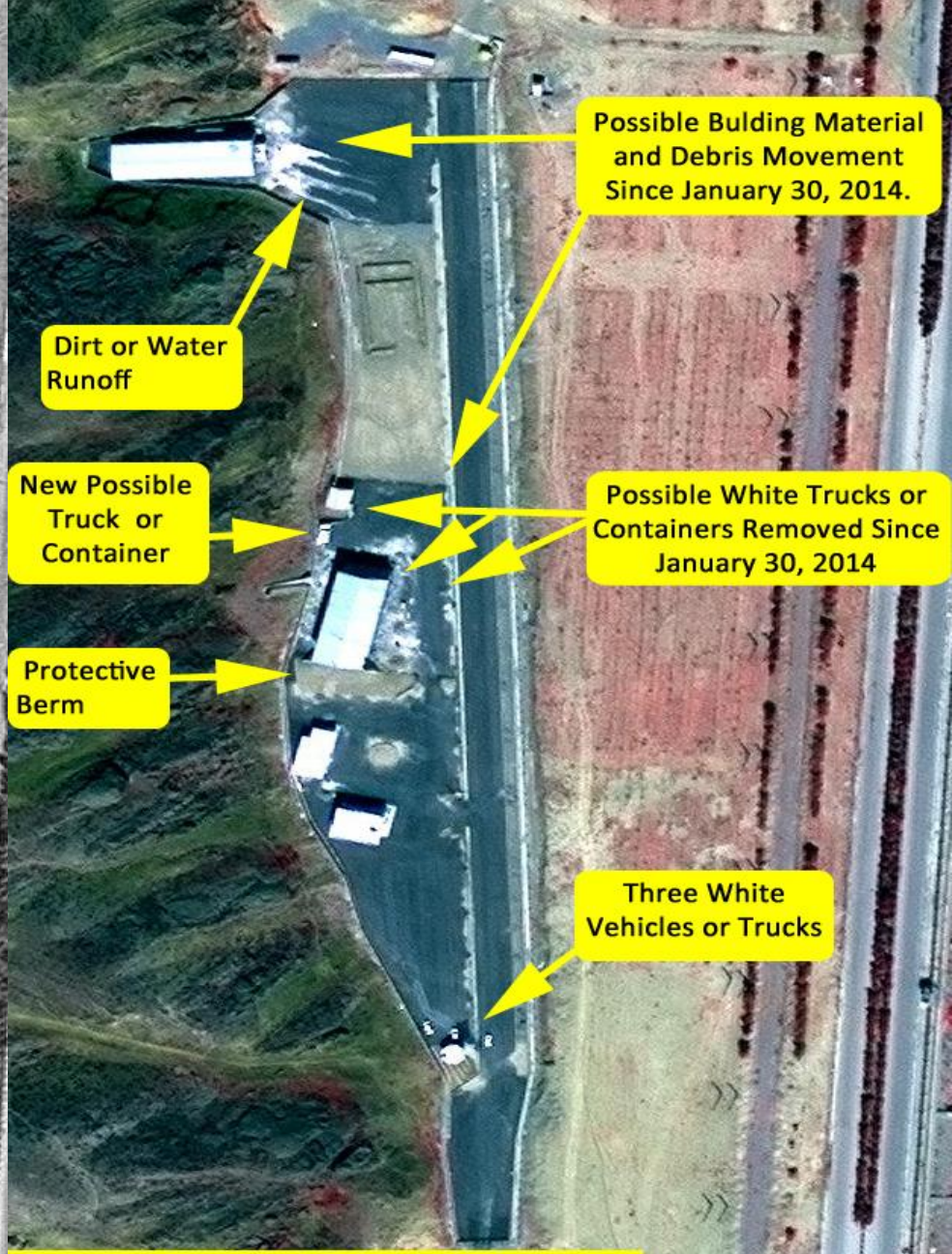


Image Credit: Digital Globe-ISIS
Image Date: April 25, 2014
Not for use without Digital Globe licensing

Digital Globe - ISIS

August 12, 2014

Not for use without licensing



New Construction Material or Debris

Vegetation Growth

Construction Material or Debris Remain

Less Construction Material or Debris

New Dirt or Water Runoff

Protective Berm

Clean-up of Dirt or Water Runoff



Airbus - ISIS
October 9, 2014

Airbus - ISIS
October 7, 2014

**Only Debris and
Water Runoff
Remain**





Site of Alleged High Explosive Activities Related to Nuclear Weapons Development Prior to 2004

Site of Possible Explosion

Airbus - ISIS
October 9, 2014

Pleiades ©CNES 2014 - Distribution Airbus DS/Spot Image



Crater

Building Demolished

Buildings Missing

Damage

Trucks and Debris

Airbus - ISIS
October 9, 2014

Pleiades ©CNES 2014 - Distribution Airbus DS/Spot Image



FORDOW, IRAN



Earth Spoils

Tunnel Entrances

Tunnel Entrances

Tunnel Entrances

Security Perimeter

Image Credit: Digital Globe - ISIS
Image Date: December 21, 2013
Not for use without Digital Globe licensing



Rare Materials Plant (RMP)

India

2/27/2011

Image Credit: Digital Globe - ISIS
Image Date: February 28, 2011
Not for use without Digital Globe licensing

Likely Uranium
Enrichment Plant

Likely New Uranium
Enrichment Plant
Under Construction

Construction of
New Buildings

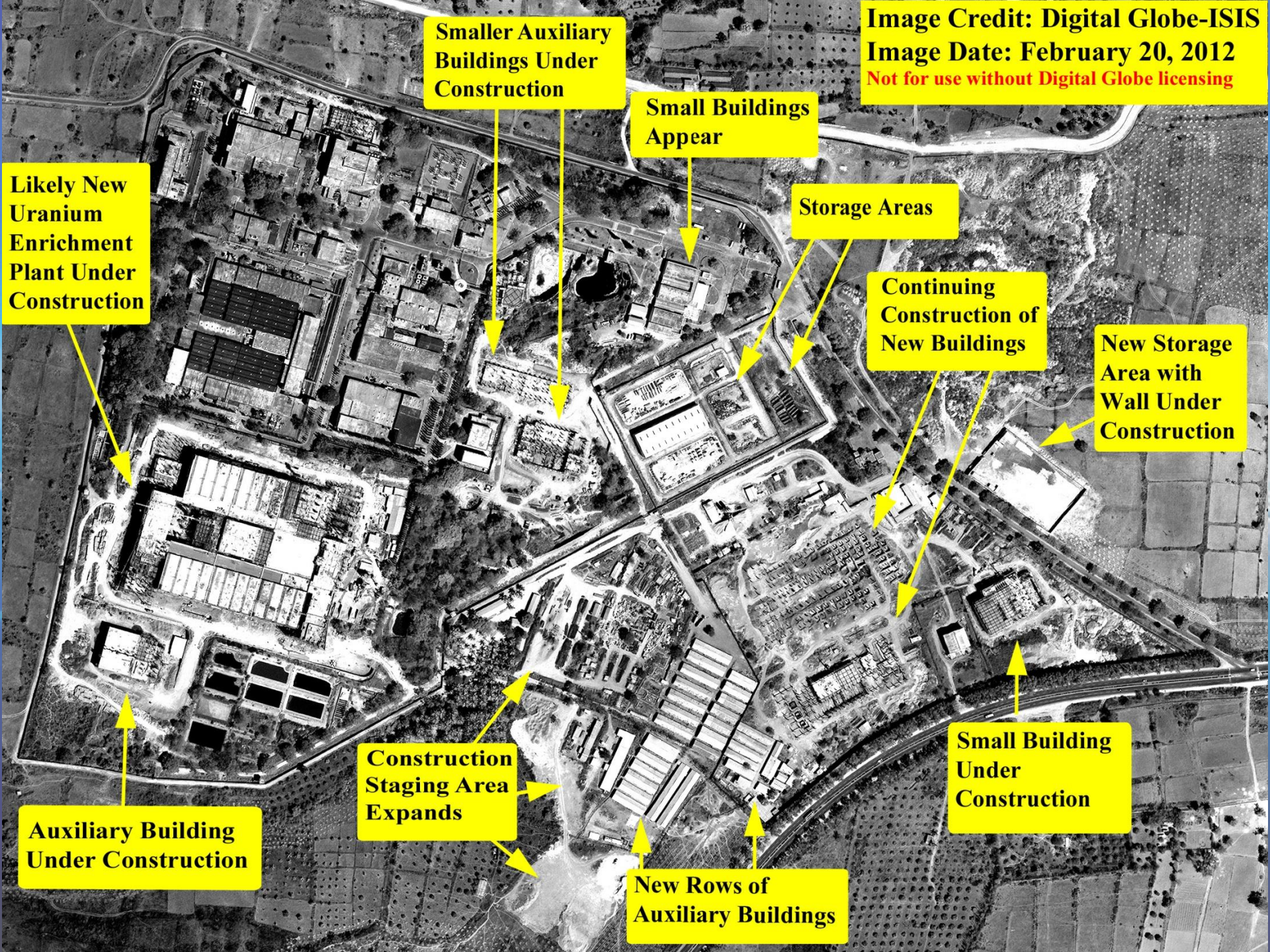
Construction
Staging Area

© 2011 DigitalGlobe

Google earth



Image Credit: Digital Globe-ISIS
Image Date: February 20, 2012
Not for use without Digital Globe licensing



Smaller Auxiliary Buildings Under Construction

Small Buildings Appear

Storage Areas

Continuing Construction of New Buildings

New Storage Area with Wall Under Construction

Small Building Under Construction

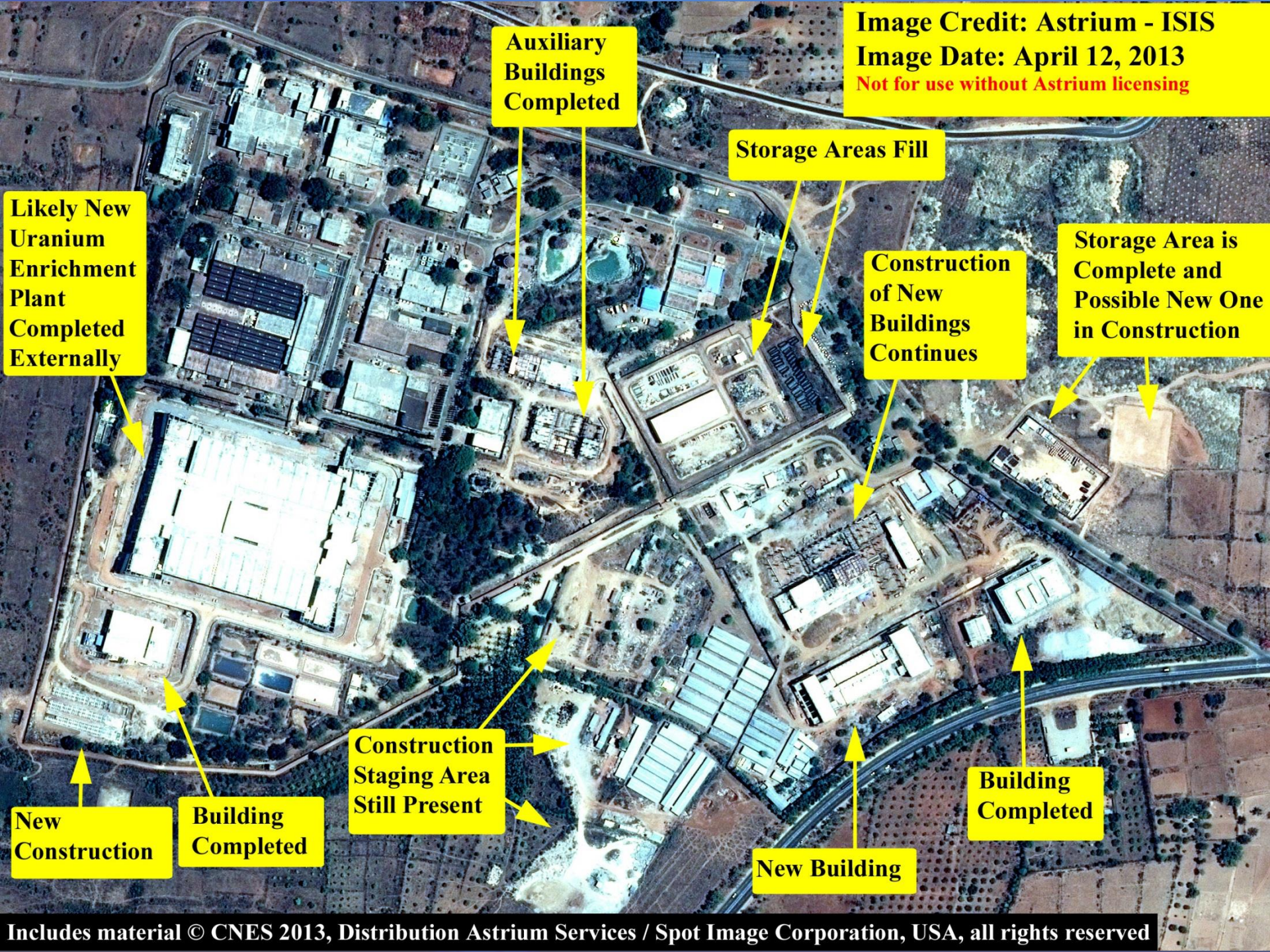
New Rows of Auxiliary Buildings

Construction Staging Area Expands

Auxiliary Building Under Construction

Likely New Uranium Enrichment Plant Under Construction

Image Credit: Astrium - ISIS
Image Date: April 12, 2013
Not for use without Astrium licensing



Auxiliary Buildings Completed

Storage Areas Fill

Construction of New Buildings Continues

Storage Area is Complete and Possible New One in Construction

Likely New Uranium Enrichment Plant Completed Externally

Construction Staging Area Still Present

Building Completed

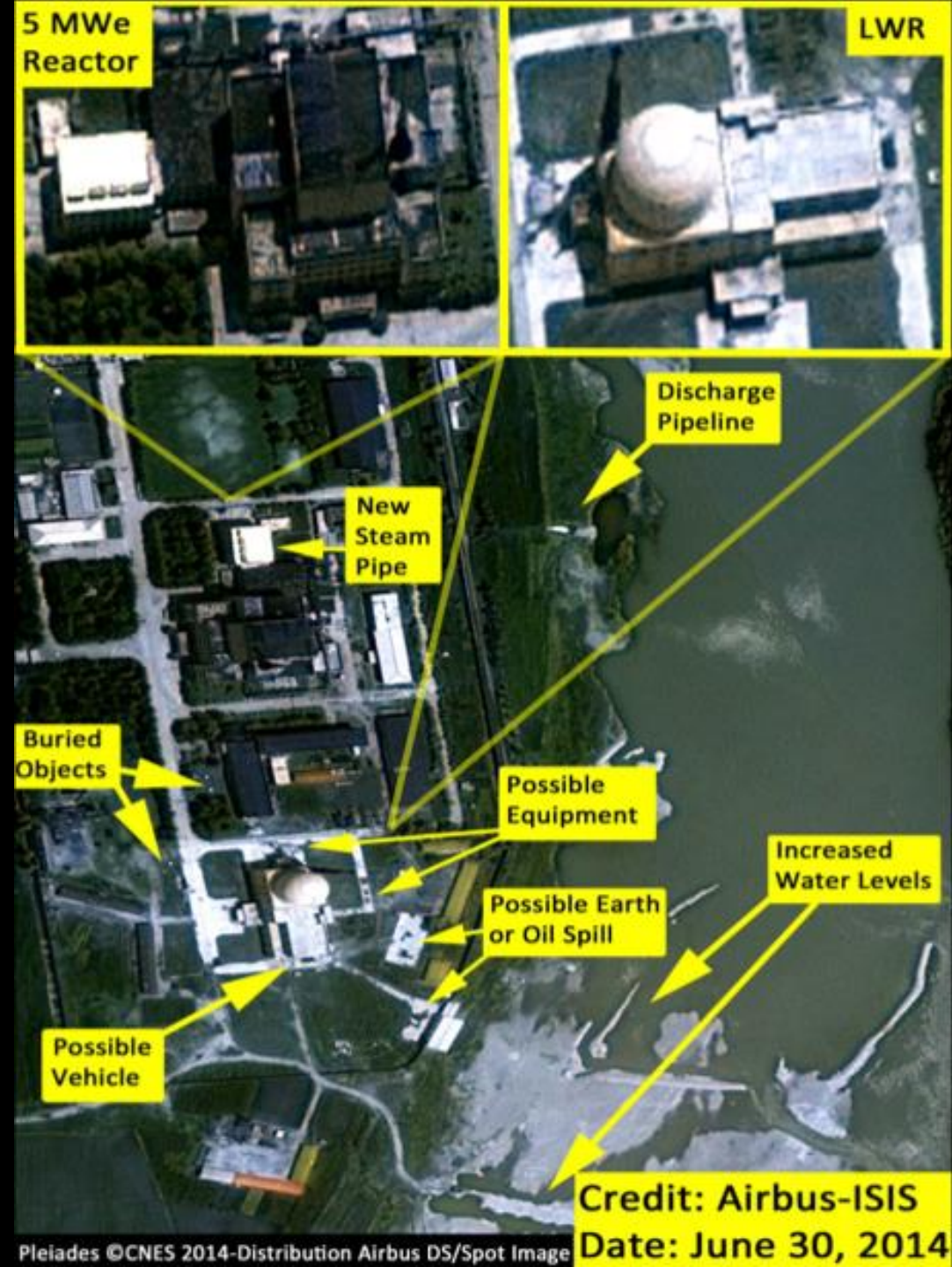
New Building

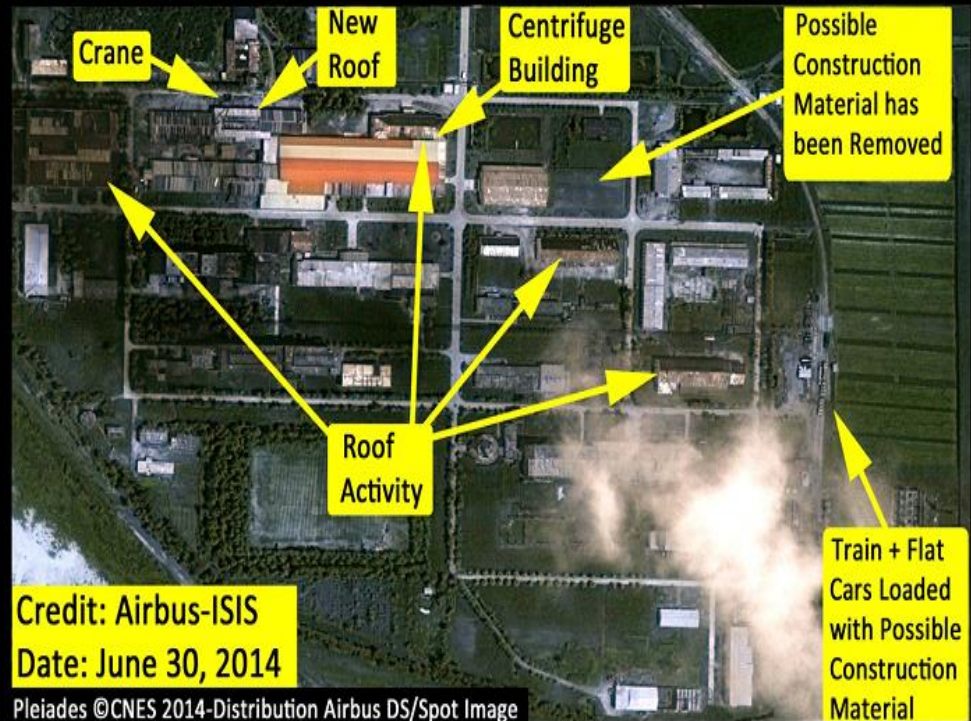
Building Completed


New Construction



Yongbyon, North Korea







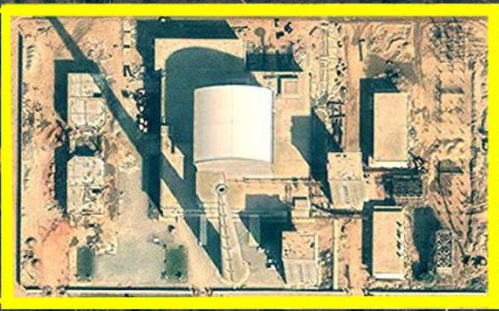
Khushab, Pakistan

Image Credit: Digital Globe - ISIS
Image Date: November 1, 2013
Not for use without Digital Globe licensing

Heavy Water Reactor 1




Heavy Water Reactors 2 and 3



Reactor 4

Heavy Water Production Plant





Punggye-ri, North Korea



west portal
site of 2009 test



east portal
site of 2006 test



south portal
likely site of third test



Image © 2013 DigitalGlobe
Image © 2013 GeoEye

Google earth

41°17'18.49" N 129°05'53.21" E elev. 1578 m

Eye alt: 4.19 km

west portal

south portal

cables

tunnel entrance

cable run

cables

road

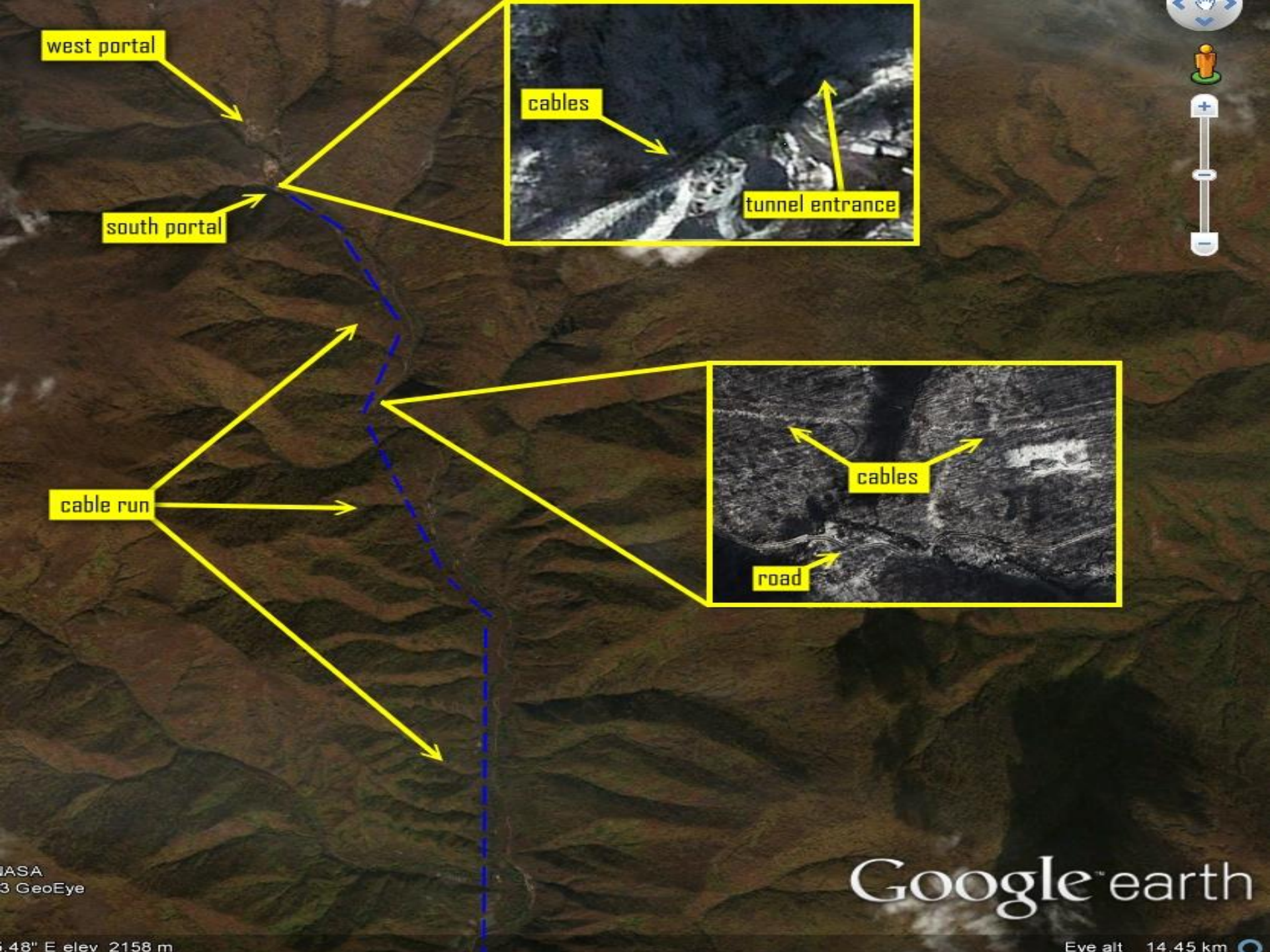


Image Credit: Digital Globe-ISIS
Image Date: April 23, 2014
Not for use without Digital Globe licensing



Truck

Main Support Area

Heavily Used Road

Tunnel Entrances

South Portal

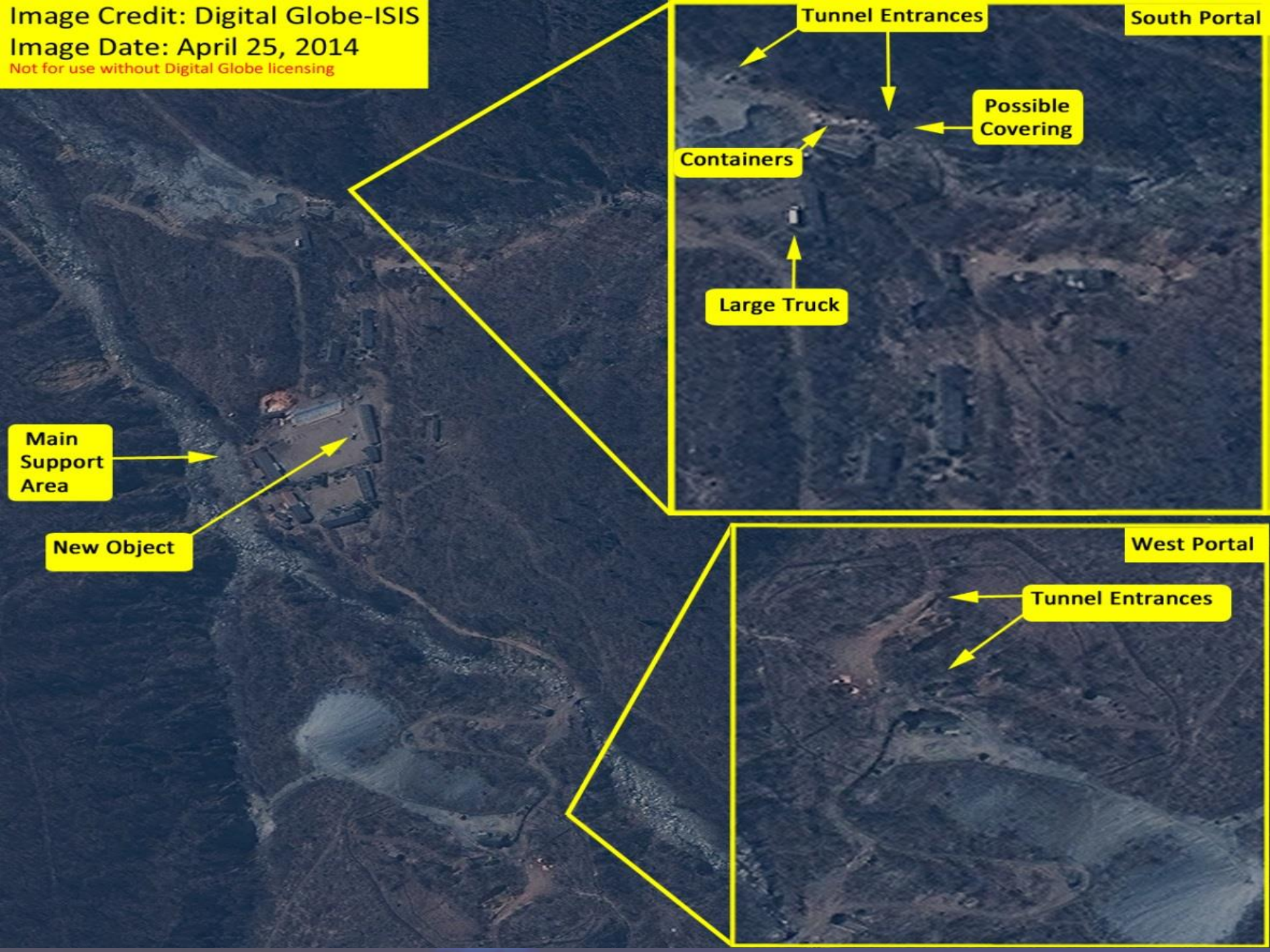
Boxes Removed Since April 19, 2014

Containers

West Portal

Tunnel Entrances

Image Credit: Digital Globe-ISIS
Image Date: April 25, 2014
Not for use without Digital Globe licensing



South Portal

Tunnel Entrances

Possible Covering

Containers

Large Truck

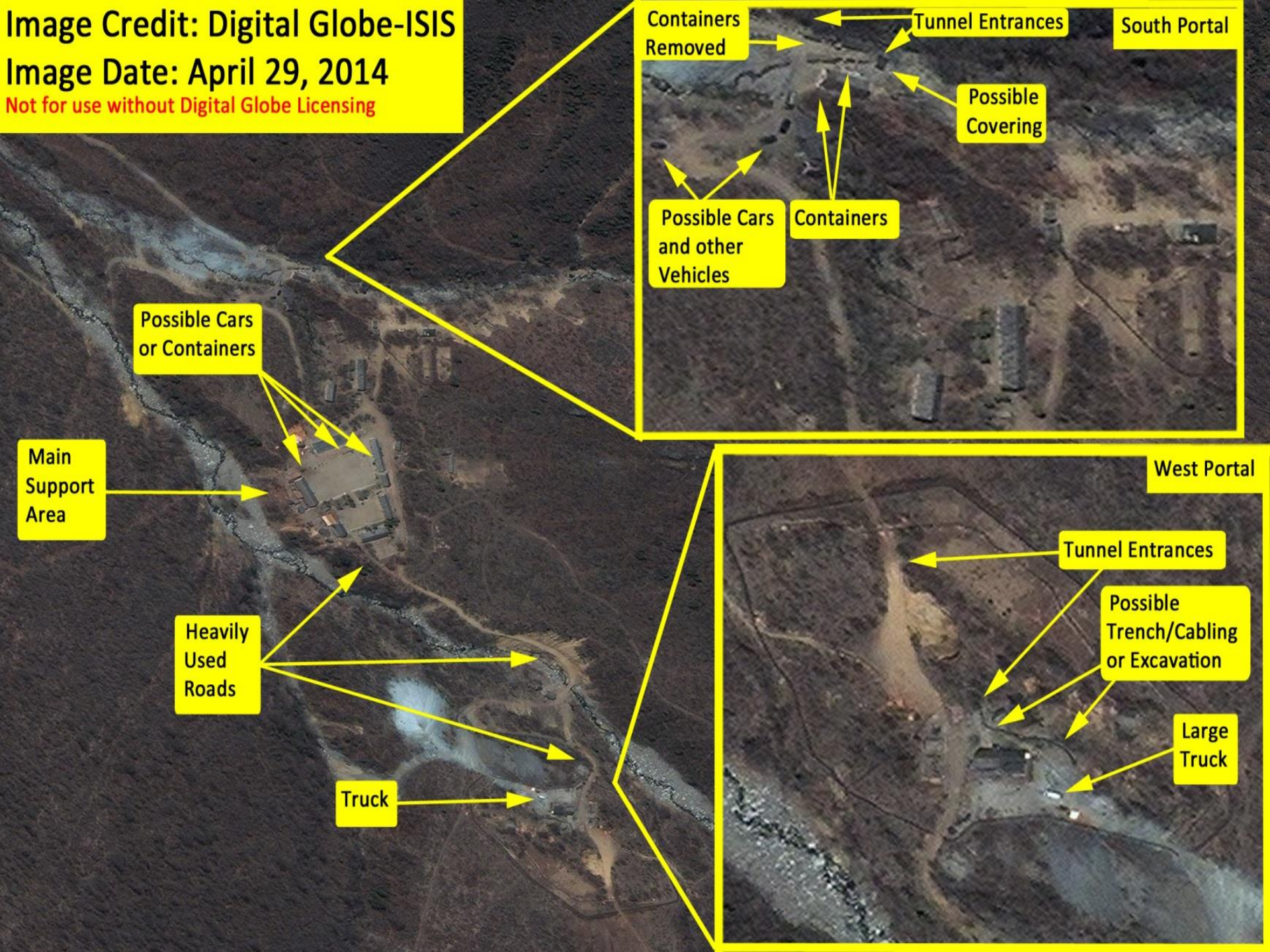
Main Support Area

New Object

West Portal

Tunnel Entrances

Image Credit: Digital Globe-ISIS
Image Date: April 29, 2014
Not for use without Digital Globe Licensing



Containers Removed

Tunnel Entrances

South Portal

Possible Cars and other Vehicles

Containers

Possible Covering

West Portal

Tunnel Entrances

Possible Trench/Cabling or Excavation

Large Truck

Possible Cars or Containers

Main Support Area

Heavily Used Roads

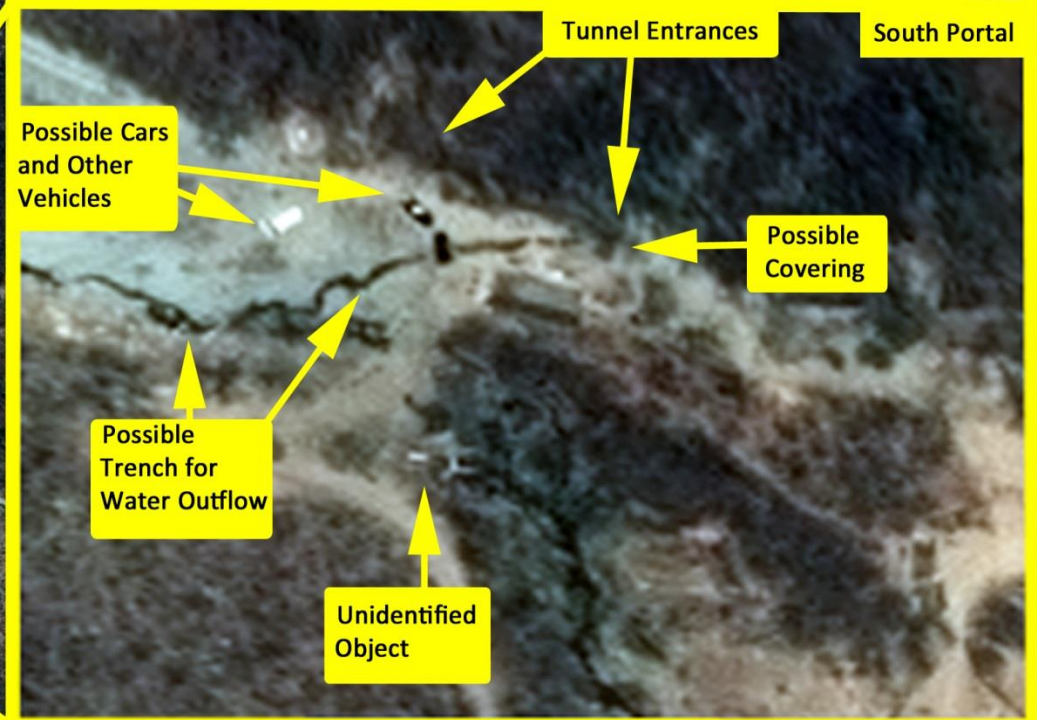
Truck

Image Credit: Airbus - ISIS
Image Date: May 1, 2014

Not for use without Airbus licensing



Main Support Area



Possible Cars and Other Vehicles

Tunnel Entrances

South Portal

Possible Covering

Possible Trench for Water Outflow

Unidentified Object



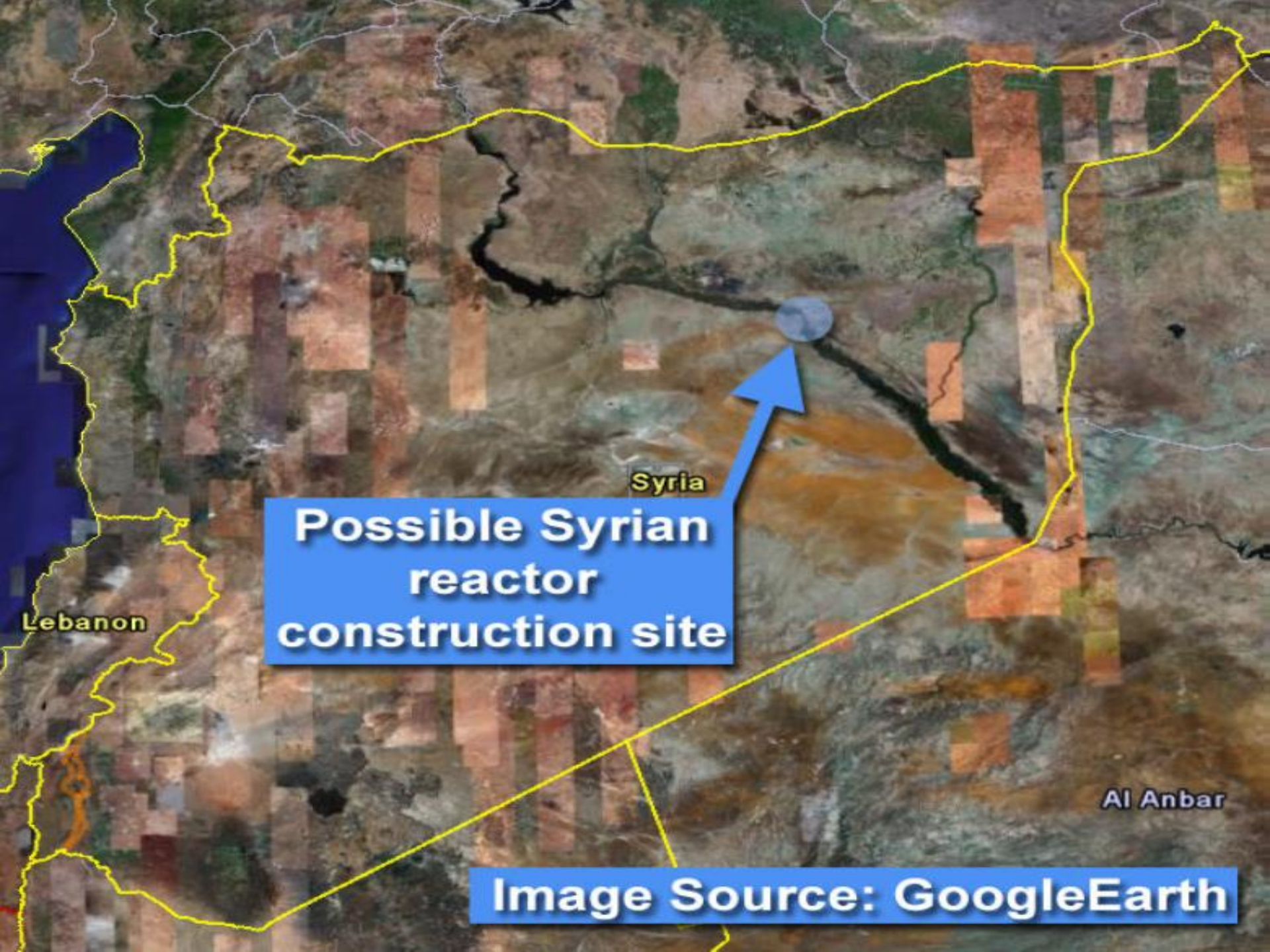
Tunnel Entrances

West Portal

An aerial view of Earth from space, showing a bright sun in the upper right corner. The Earth's surface is covered in white clouds, and the blue of the atmosphere is visible. The sun is positioned in the upper right quadrant, creating a lens flare effect. The Earth's horizon is visible as a curved line across the middle of the frame.

“Wide Area Searches”

**The Case of
Al Kibar, Syria**



**Possible Syrian
reactor
construction site**

Image Source: GoogleEarth

Image Credit: DigitalGlobe - ISIS
Image Date: 10 August 2007



Airfield

**Euphrates
River**

**Possible
Syrian reactor
construction site**

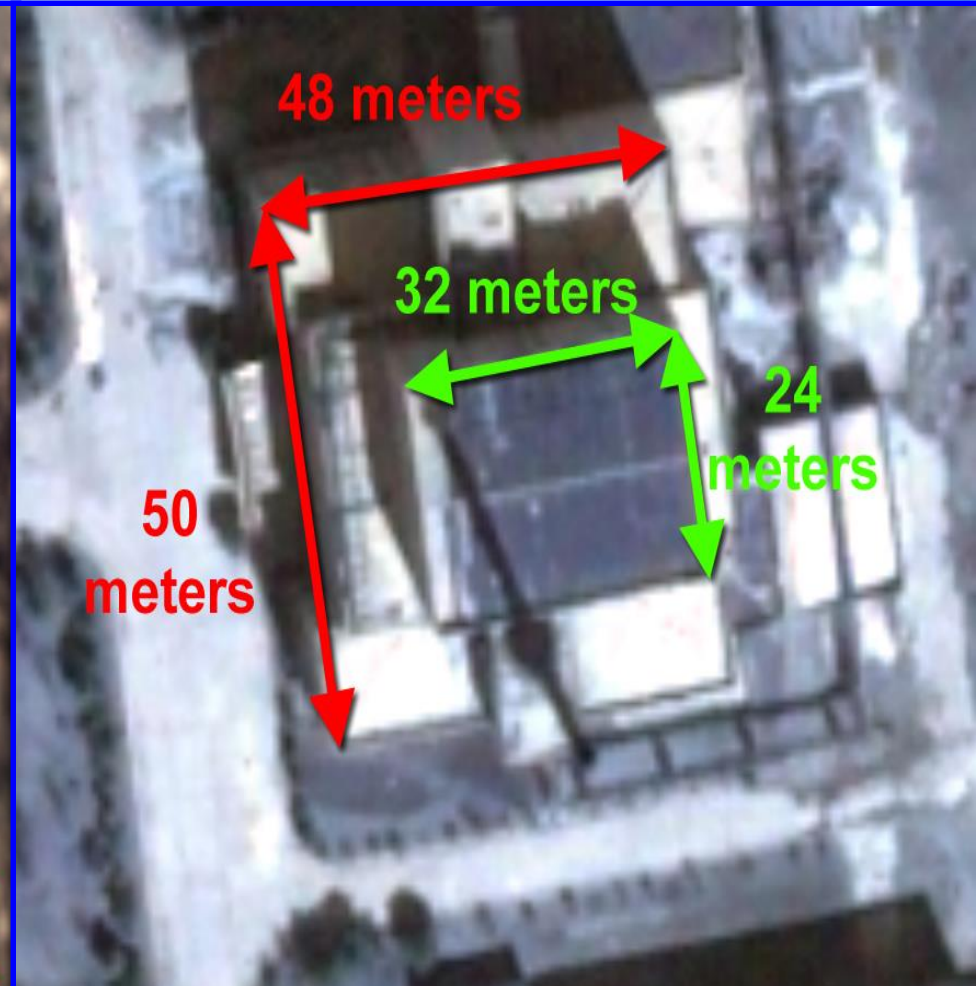


Composite of Syrian suspect site and Yongbyon 5 MW

Suspect Site, Syria



Yongbyon 5 MW





**The Case of
Lashkar Ab'ad, Iran**

Image Credit: DigitalGlobe - ISIS
Image Date: June 5, 2003
Not for use without DigitalGlobe licencing

Water Tower

Auxiliary and Support Buildings

Original Enrichment Building



Image Credit: DigitalGlobe - ISIS
Image Date: January 17, 2013

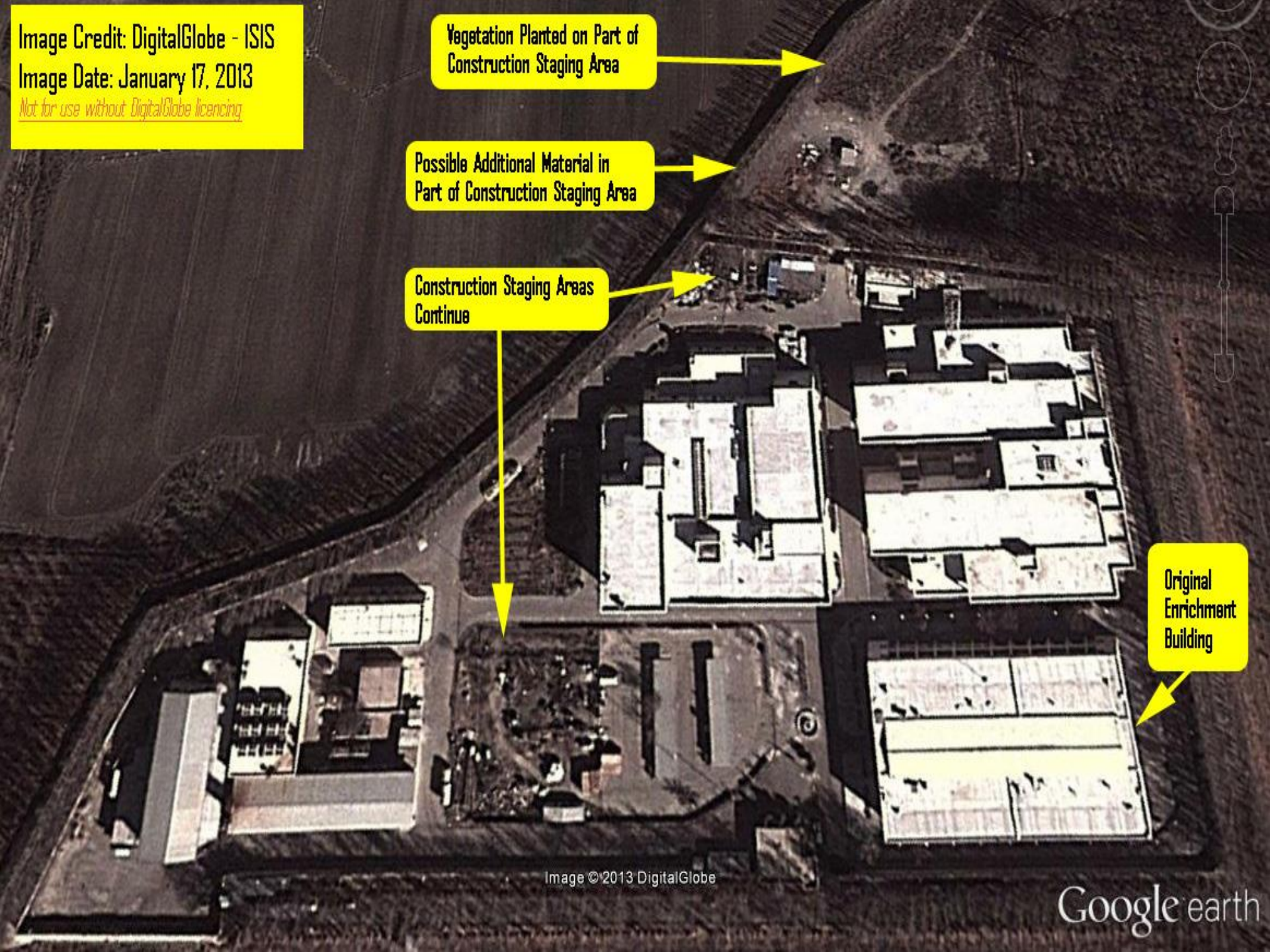
Not for use without DigitalGlobe licencing

Vegetation Planted on Part of
Construction Staging Area

Possible Additional Material in
Part of Construction Staging Area

Construction Staging Areas
Continue

Original
Enrichment
Building



Iranian National Center of Laser Science and Technology (INLC)





**Special Materials Enrichment Plant
(SMEF), India**

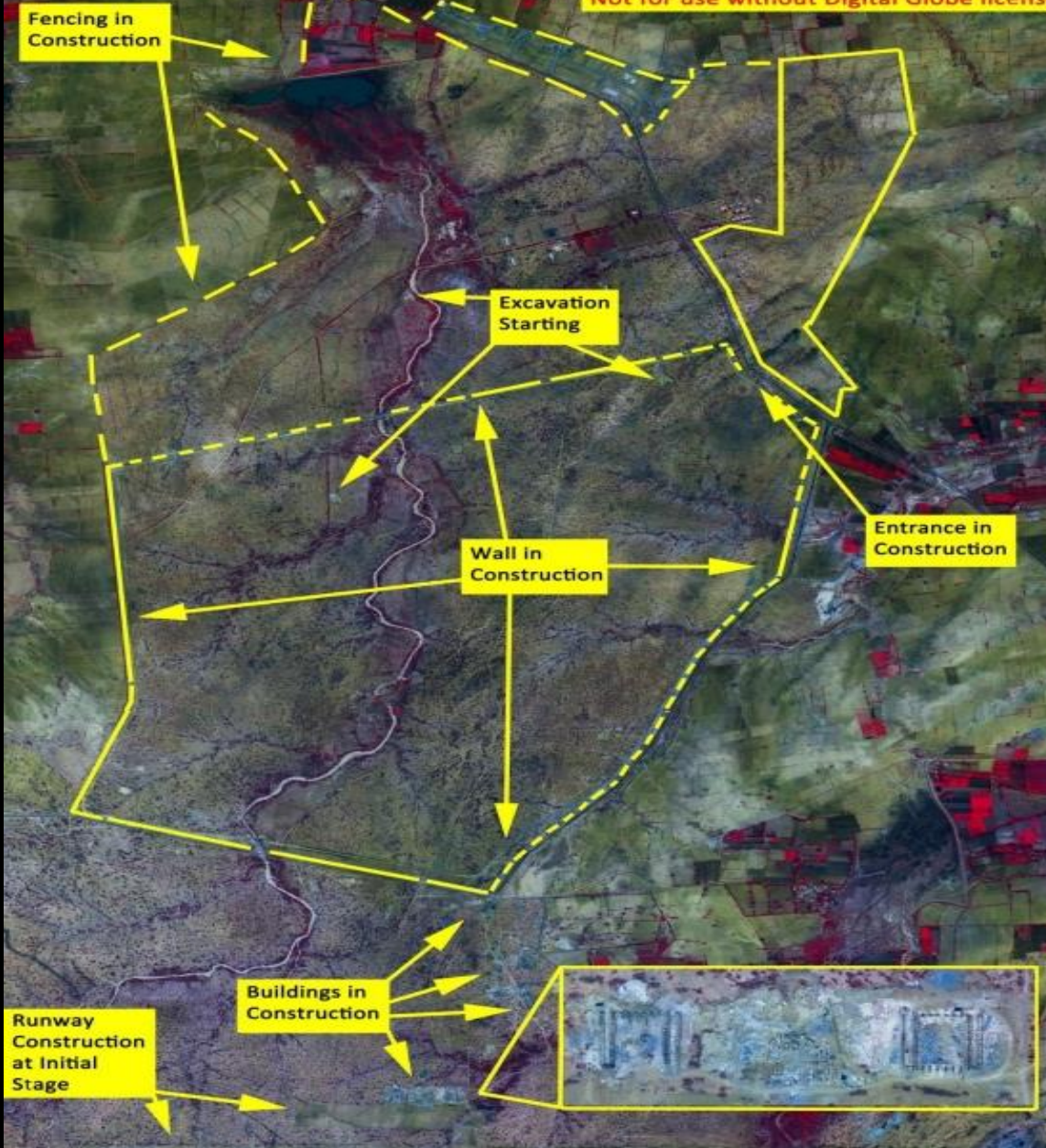
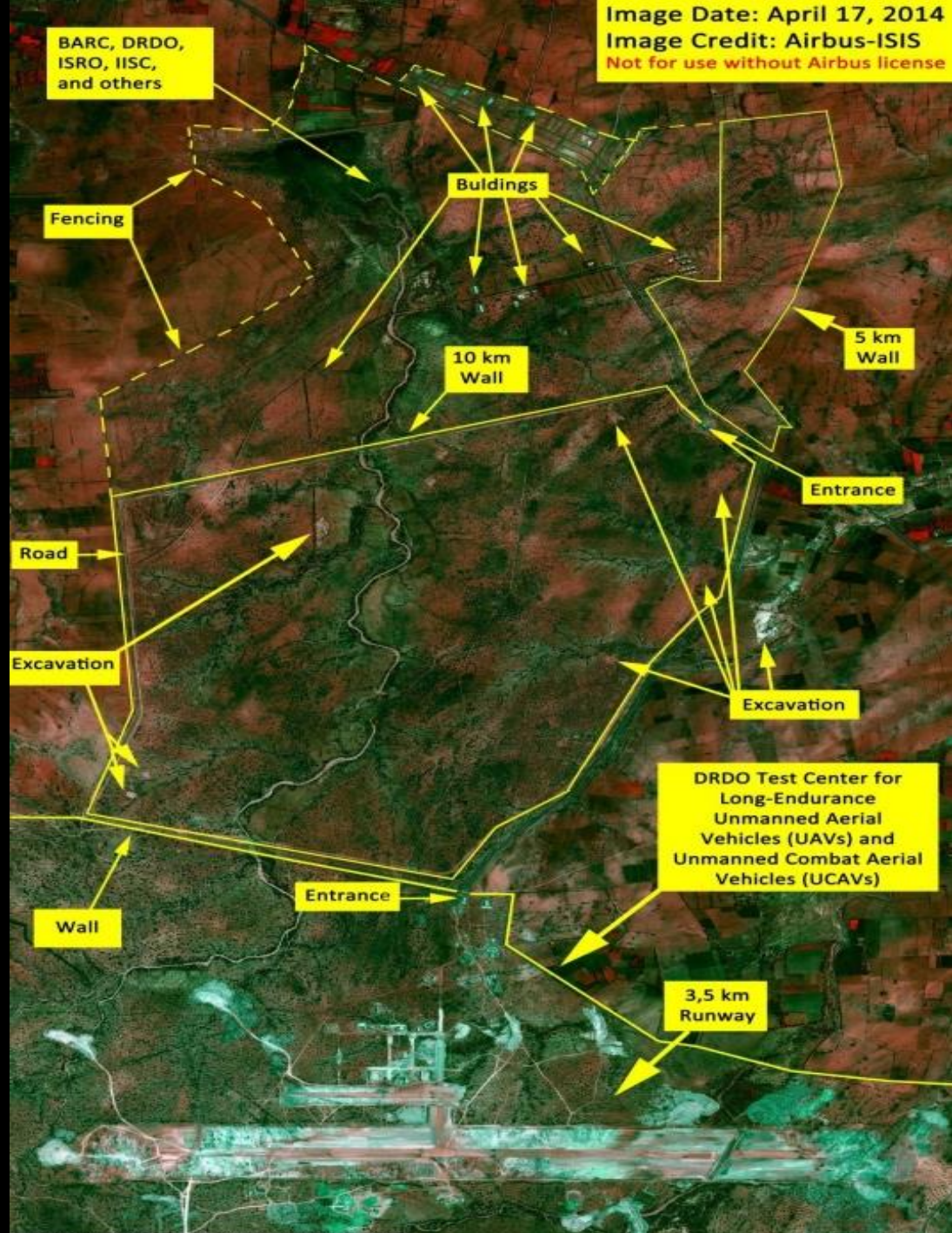


Image Date: April 17, 2014
Image Credit: Airbus-ISIS
Not for use without Airbus license



BARC, DRDO,
ISRO, IISC,
and others

Buldings

Fencing

10 km
Wall

5 km
Wall

Entrance

Road

Excavation

Excavation

DRDO Test Center for
Long-Endurance
Unmanned Aerial
Vehicles (UAVs) and
Unmanned Combat Aerial
Vehicles (UCAVs)

Entrance

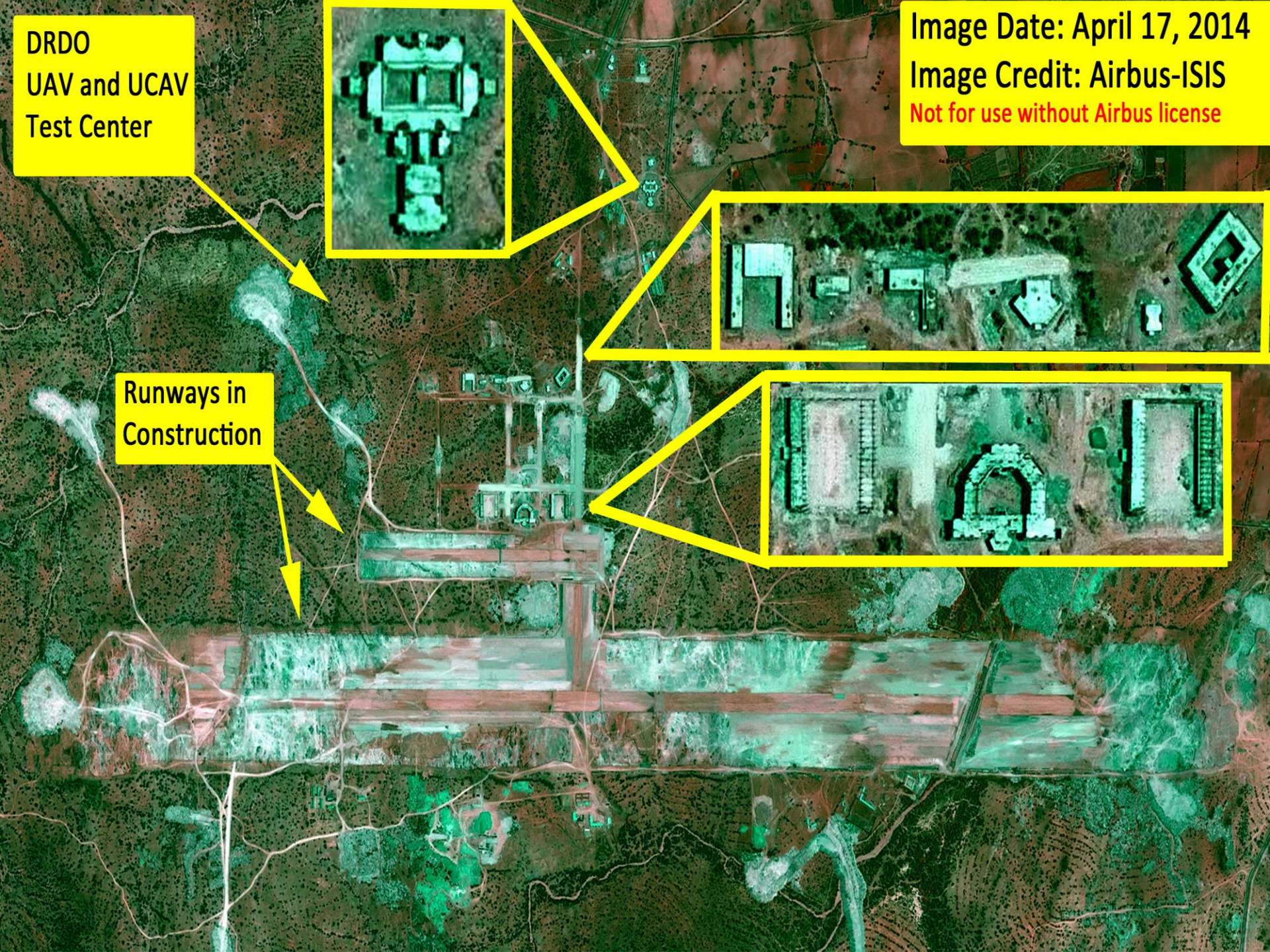
Wall

3,5 km
Runway

DRDO
UAV and UCAV
Test Center

Image Date: April 17, 2014
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Runways in
Construction



Thank You

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David Albright

albright@isis-online.org

Serena Kelleher-Vergantini

vergantini@isis-online.org