# Pyongyang advances its nuclear program while talks remain stalled

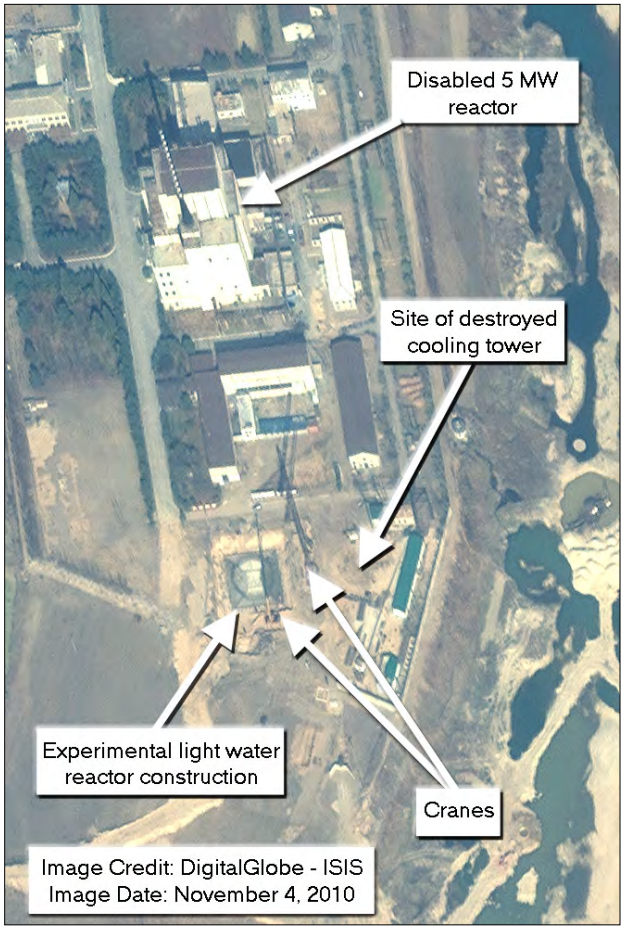
Siegfried S. Hecker
Center for International Security and Cooperation
Dept. of Management Science and Engineering
Stanford University

Presentation at Korea Institute of Nuclear Nonproliferation and Control (KINAC)
Daejeon, ROK
December 15, 2011

# OUTLINE

- **November 2010 visit to Yongbyon**
- **Status of DPRK nuclear program at that time**
- **Nuclear progress in 2011**
- **What now?** (One scientist's view)

# November 2010 visit to Yongbyon presented us with a new reality

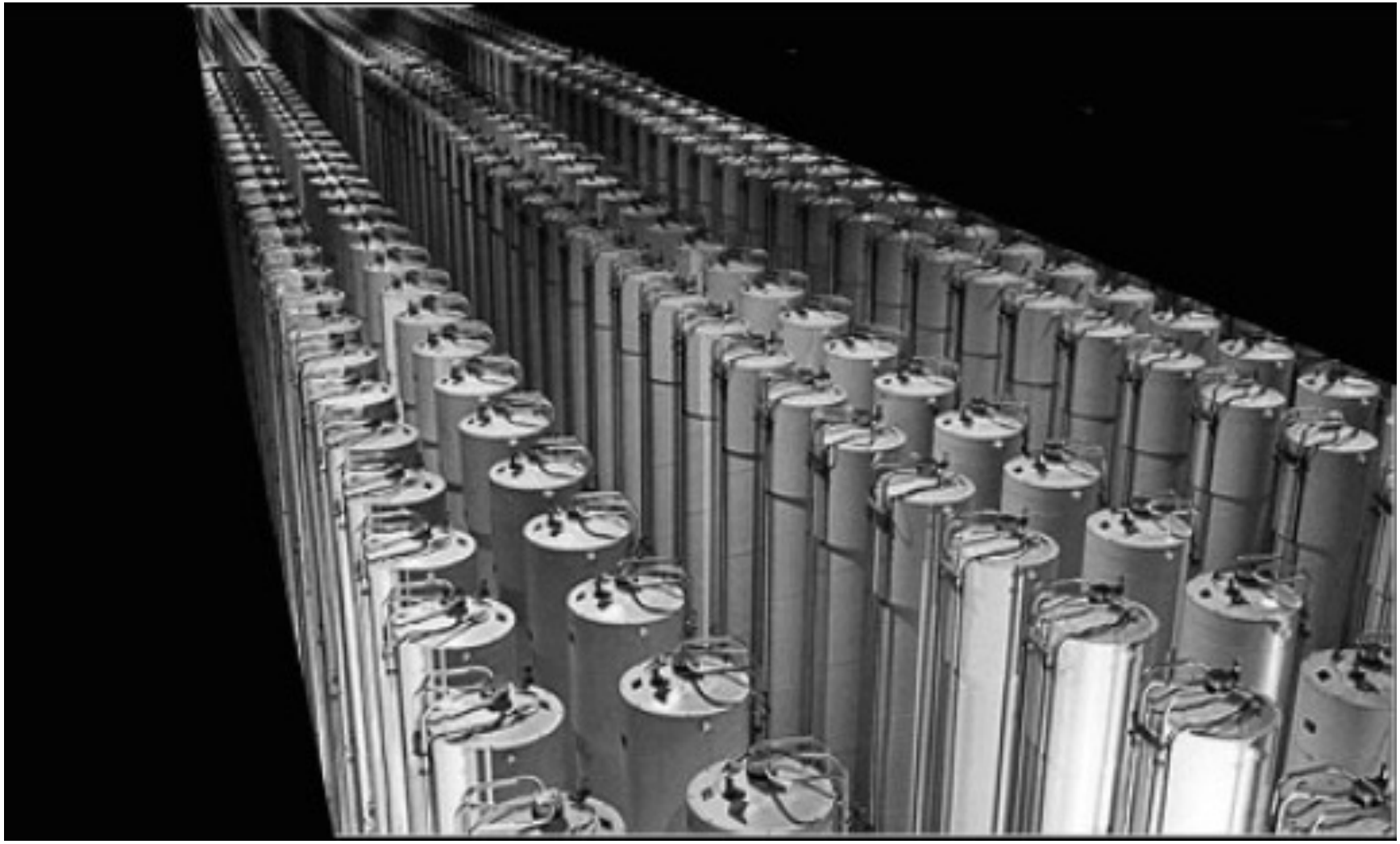




**"We will convert our center to an LWR and pilot enrichment facility. No one believed us when we announced this in 2009 - including you, Dr. Hecker,"** DPRK Official, Nov. 2010


Dr. Hecker, you will have very big news
Nov. 11, 2010

**Purely illustrative - this is not Yongbyon, but close to what we saw.**



Piketon, Ohio Centrifuge plant, 1984 (Department of Energy)
Several additional centrifuge lines were removed graphically to try to get this as close as possible to the centrifuge cascades we saw in Bldg. 4 at Yongbyon

# Kim Il-sung University e-Library

5 MWe reactor control room

# We did not discover a secret facility – they showed it to us

Jan. 2004 Yongbyon

Aug. 2005 Pyongyang

Nov. 2006 Pyongyang

August 9, 2007, Yongbyon

Feb. 14, 2008, Yongbyon

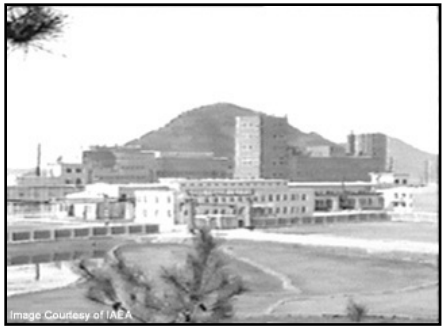
Feb. 27, 2009, Pyongyang

**Six previous visits prepared the way**

# North Korea mastered the full plutonium fuel cycle

**Front end of fuel cycle** (reactor fuel)

- Mining to fabrication of natural uranium fuel
- No enrichment required




Fuel fabrication

**Reactors** (produce Pu, electricity & heat)

- 5 MWe gas-graphite reactor (currently shut down)
  - Capable of ~ 6 kg Pu/year (one bomb's worth)
- 50 MWe construction - not finished
- 200 MWe construction halted in 1994 – not finished

5 MWe reactor

**Back end of fuel cycle** (extract Pu, manage waste)

- Reprocessing facility using Purex process

**After initial nuclear training by Soviets, DPRK built these indigenously**


Reprocessing Facility

# Here is what DPRK gave up


**5 MWe reactor**

Shut down in 2007
In stand-by mode
(6 kg Pu per year)


**50 MWe reactor**

~ 10 bombs/yr
Not completed because of Agreed Framework in 1994

**200 MWe reactor Taechon**

~40 bombs/yr, Not completed

# DPRK nuclear status in November 2010

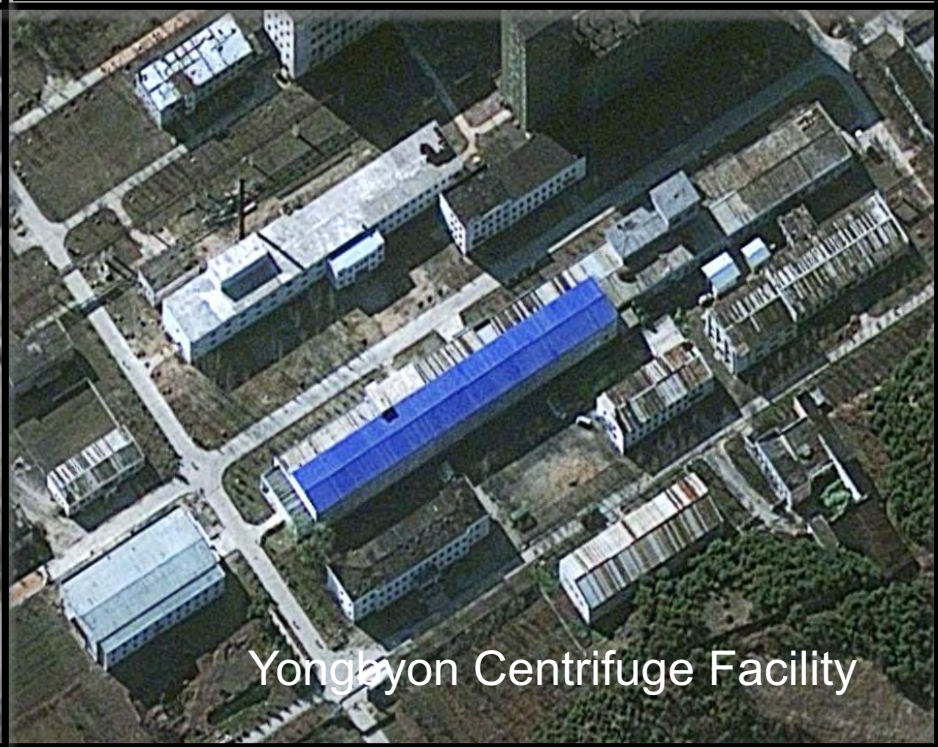
- Plutonium: 24 to 42 kg (~4 to 8 bomb's worth)
- Nuclear weapons (~4 to 8 primitive bombs)
  - Limited by plutonium and sophistication (lack of testing)
- No plutonium in the pipeline – reactor not restarted
  - Would require 6 months to restart, 2 years to make more plutonium
- Potential nuclear test – needed for miniaturization for missiles
  - Plutonium test possible – but very little available
  - HEU as alternative?
- Uranium enrichment
  - Likely long-standing R&D effort but denied by DPRK
  - Small industrial scale apparently operational now at Yongbyon
  - Other centrifuge facilities must exist – possibly produce HEU
- Concern about nuclear imports, exports and cooperation

## DPRK nuclear advances in 2011

- **Experimental Light-water reactor (LWR)**
- **Uranium enrichment**
- **Ballistic missiles**


Musudan road-mobile missile


Yongbyon Exp. LWR


Yongbyon Centrifuge Facility

# Experimental light-water reactor (LWR) construction

- **25 to 30 MWe (100 MW-thermal)**
  - We will start small, learn, then build a larger power reactor
- **Reinforced concrete containment shell started**
  - 22 m diam by 40 m high (excavation 7.1 m deep)
- **Steel pressure vessel**
  - To be manufactured indigenously
- **Two electrical generators for electricity**
  - Local communities and linked to national grid
- **Uranium dioxide ($UO_2$) fuel pellets in cladding**
  - Not yet decided (either zircaloy or stainless steel)
- **Fuel to be enriched (LEU) to 3.5% U-235**
- **Target completion date - 2012 (I believe, unrealistic)**

**Their claim that Yongbyon is being converted to LWR and uranium enrichment is credible**


Figure 2. A November 2010 satellite image of the Experimental LWR with only the foundation visible. Image Credit: Includes GeoEye-1 and/or IKONOS Products © GeoEye, distributed by e-GEOS. http://38north.org/2011/11/elwr111411/picture2/


14 November 2011, Source: GeoEye; AP, IHS Jane's

# Motivation and history of LWRs for North Korea

- **North Korea chose gas-graphite reactor design in '70s**
  - Poor for electricity, good for bombs (like early UK and France)
- **By 1980s realized difficulty of nuclear electricity supply**
  - 1985 agreement to get two Soviet LWRs – never implemented
- **1994 Agreed Framework**
  - U.S., ROK, Japan to provide two modern LWRs - unfulfilled
- **Aug. 2005 meeting with Vice Minister Kim Kye-gwan**
  - No LWR, no deal - referring to Joint Statement (signed 9/19/05)
- **Aug. 2007 meeting with VM Kim Kye-gwan**
  - U.S. can run the LWR, we won't enrich, won't reprocess
- **2009 decision after rocket and nuclear test and sanctions**
  - We'll do it alone - begin experimental LWR and enrichment

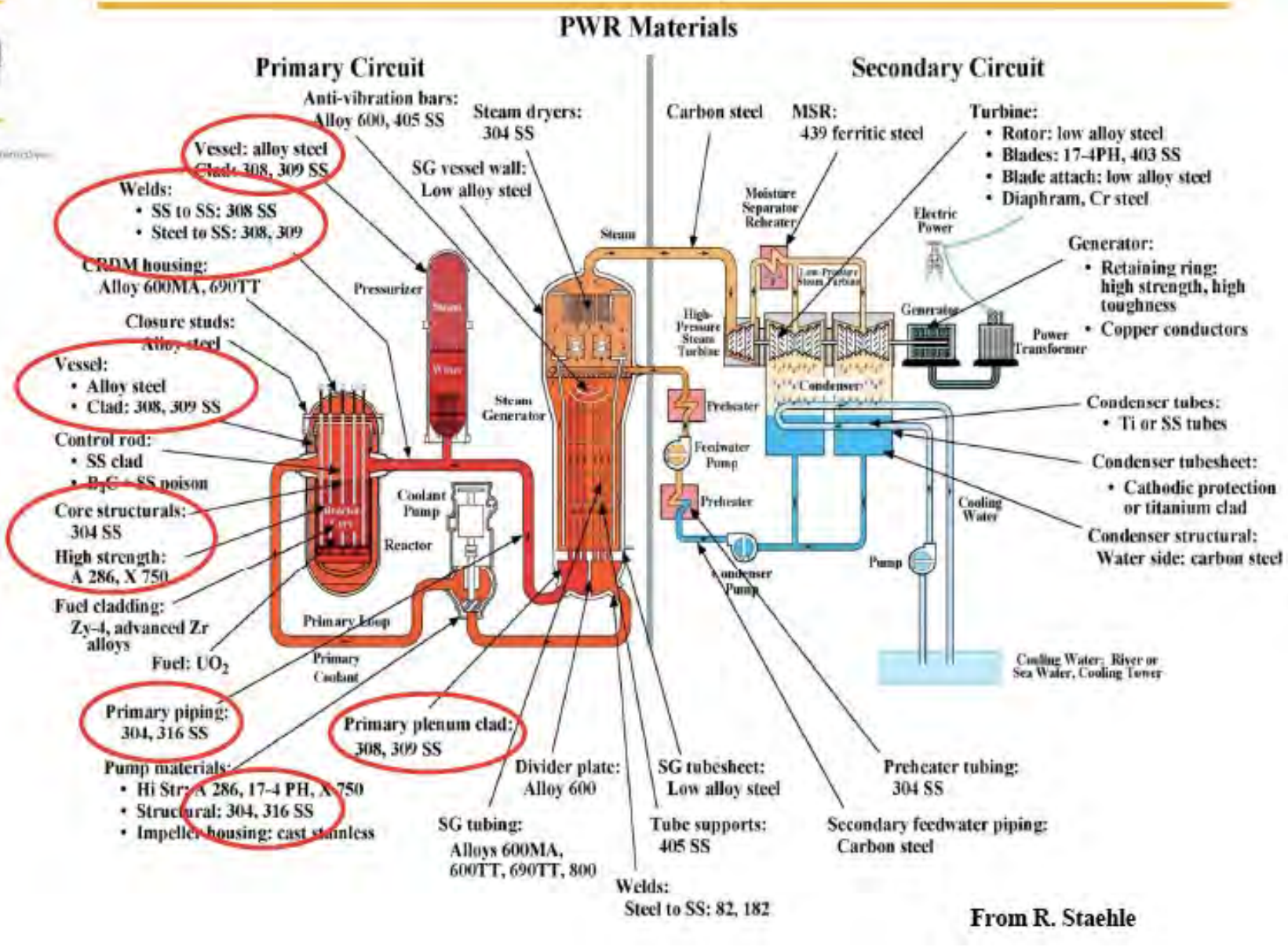
**The LWR has economic and symbolic importance.**
**I believe LWR is designed for electricity**

# Some potential concerns about the LWR?

- **Plutonium production** **(not a major concern)**
  - Like all uranium fueled reactors, this LWR will produce plutonium
  - Typical LWR plutonium is not very suitable for bombs
  - The existing 5 MWe reactor can produce 6 kg/year of super-bomb grade plutonium

- **LWR requires uranium enrichment**
  - Centrifuge facilities that produce LEU (3.5% U-235) can readily be reconfigured to make bomb-grade HEU (~90% U-235)

# LWR has very different critical requirements from gas-graphite reactors




From R. Staehle

# Most serious LWR concern is nuclear safety

- **Safety -** can it be constructed and operated safely?
  - Nuclear regulatory approval and oversight is imperative
    - DPRK claims to have a National Nuclear Safety Commission
    - Is NNSC staffed adequately?
    - It is surely not sufficiently independent
  - LWR is a new design - entirely new design team at work
    - Many questions remained about materials and fabrication at time of our visit
  - DPRK has not benefitted from lessons of previous accidents
  - Lessons of Fukushima
    - DPRK reactor is different design (PWR not BWR)
    - No experience with demanding materials and fabrication issues
    - Emergency response and disaster management – unprepared

# Fukushima Daiichi: Station Blackout. Importance of nuclear regulatory structure, disaster response and emergency management

# North Korea is not prepared for disasters

(AP Photo/APTN)

## Heavy flood damage in North Korea – Aug. 2007

- > 50 cm of rain
- > 600 people dead
- 200,000 – 300,000 homeless

Aug. 9, 2007

- 450,000 tons crops lost
- > 10% of corn and rice fields washed away or buried

# Uranium Enrichment Facility

# The new Yongbyon centrifuge facility

- **2,000 centrifuges in a divided 100-meter cascade hall**
- **Centrifuges ~ 6 ft high by 8 in diameter**
- **Claimed to have steel rotors**
  - Likely maraging steel, hence P-2 (G-2) centrifuges
- **Through-put claimed at 8,000 kg SWU/year**
  - Capable of producing 2 tonnes LEU/yr (adequate for small LWR)
- **Claimed to be operating, producing LEU now**
  - We cannot confirm, but not inconsistent with what we saw
- **Modern control room**

**Facility and capacity is consistent with fuel requirements for experimental LWR**

# My previous assessment of uranium enrichment

**Of course, DPRK has a program… …**
**but only at the R&D level**

- **2004 visit - Yongbyon official tells J.W. Lewis of early UE**
  - But subsequently denies statements
- **1990s - connections to Pakistan's A.Q. Khan and KRL**
- **Late 1990s - global procurement attempts**
- **2002 CIA analysis is plausible**
- **Remarkably quiet since then - until Nov. 12, 2010**

# How did North Korea get enrichment and when?

- **What we saw requires many years of development, manufacture and testing** – not started in April 2009 as claimed
- **Most likely decades of R&D, procurement and training**
- **HEU particles in North Korea and $UF_6$ to Libya questions**
- **Current configuration likely tested outside Yongbyon**
  - Another centrifuge facility dedicated to HEU possible
- **Unlike the original reactors, centrifuges require help***
  - Cooperation with Pakistan's A.Q. Khan since 1993
  - Included training of their technical specialist at Khan Research Lab
  - Supply of two dozen centrifuges by Khan around 2000
  - Complex web of procurement - i.e. aluminum from Russia & Germany
- **Possible cooperation with Iran**

* See D. Albright and P. Brannan, "Taking Stock: North Korea's Uranium Enrichment Program, ISIS, Oct. 8, 2010

# Why uranium enrichment?

- **Fuel for LWR**

- **HEU for bombs or warheads**
  - HEU provides the most certain route to simple bomb
  - May be viewed as quicker route to miniaturized warhead
  - But, only with outside help (A.Q. Khan, Tinner family, Iran ?)
  - Uranium enrichment is easier to hide
  - May be able to scale up more easily

- **Uranium enrichment offers better export potential**

**Uranium enrichment is dual use – the "Iran problem"**

**Musudan Missile and TEL**
Pyongyang Parade: 10 October 2010 AP Wide World

- **Miniaturization combined with missiles is dangerous**
- **Especially road-mobile Musudan (aka Soviet R-27)**
- **Strengthens Pyongyang's case for a deterrent**

# Nuclear threat increased in 2011

- **LWR reactor construction continues**
  - Should they be stopped or helped to make it safe?
- **Uranium enrichment**
  - We know so little – major concerns about HEU production
- **Musudan missile emerges as possible delivery delivery vehicle for nuclear warhead**
  - Concerns about missile test and nuclear test

# What are the nuclear security threats?

- **Nuclear attack – currently, a low threat**
  - Concerns in event of miscalculation or instability
  - Greater threat if many more bombs
- **Miscalculations, instability or accidents – possible**
- **Uranium enrichment (HEU) – low** unless lots of HEU
- **Export – materials or technologies – very serious**
  - Centrifuge technologies may be attractive
  - HEU export bigger threat than plutonium

# Will DPRK give up the bomb?

- Not in the near future - not voluntarily
- Must have price of keeping weapons be be greater than benefits
- China holds the key to the price – U.S. and ROK hold the key to benefits

**We must understand why DPRK wants weapons. Security, domestic and international reasons.**

# A risk reduction approach forward

- Re-engage to stop nuclear threat escalation
- Stay the course on denuclearization, but limit threat
- Initial confidence-building measures – missile test and nuclear test moratorium in return for what DPRK values
- Then - three no's and a yes
  - No more bombs (no plutonium or HEU)
  - No better bombs (no nuclear and no missile tests)
  - No export or import
- Yes - address fundamentals of North Korea's insecurity

# Time is not on DPRK's side

Cell phones in Nov. 2010

# BACKUP


Figure 2. A November 2010 satellite image of the Experimental LWR with only the foundation visible. Image Credit: Includes GeoEye-1 and/or IKONOS Products © GeoEye, distributed by e-GEOS. http://38north.org/2011/11/elwr111411/picture2/

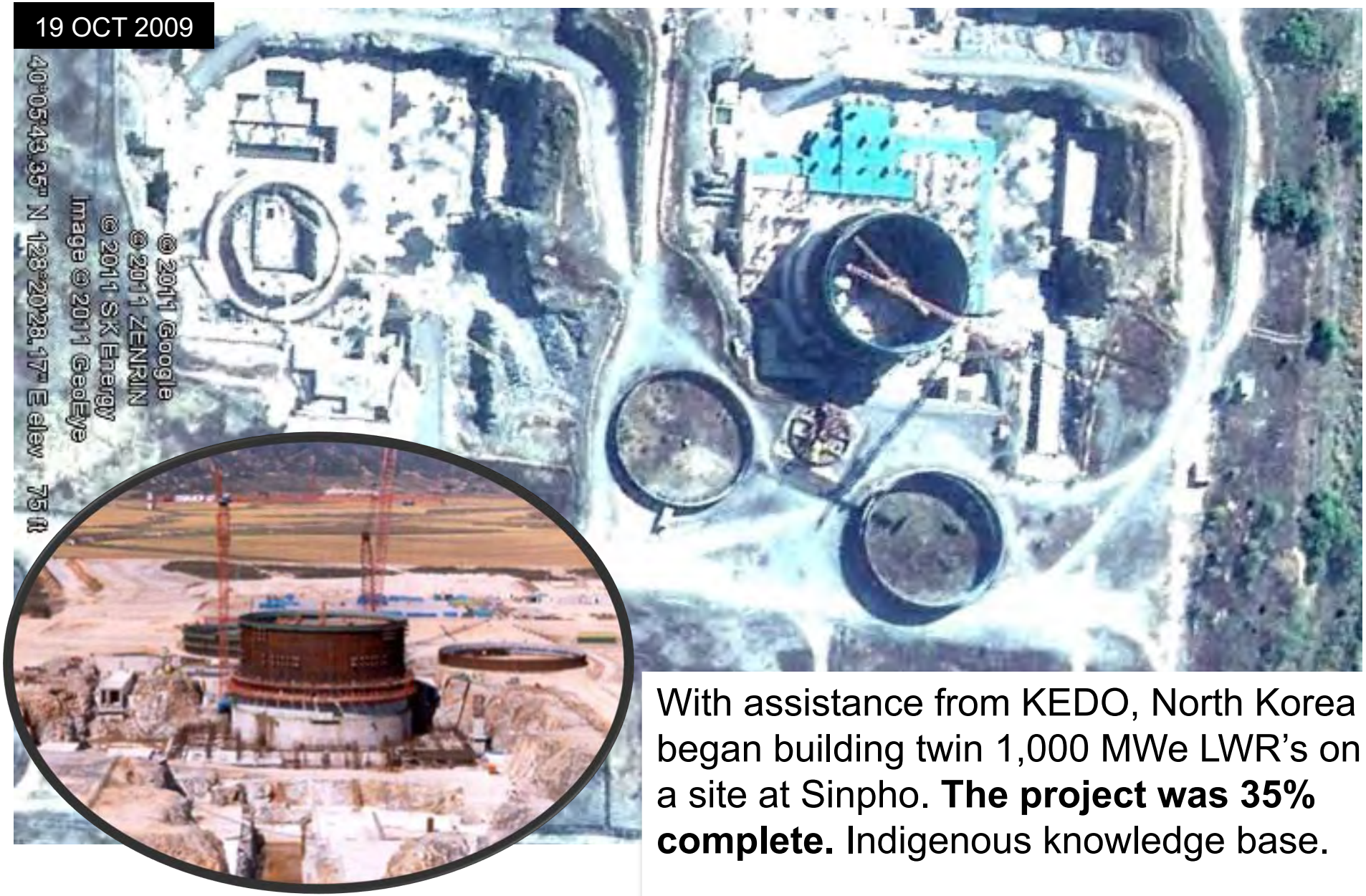

Figure 3. By May 22, 2011, in addition to further construction progress, there are pipe traces to the river for supplying cooling water and hot water discharge. Image Credit: Includes GeoEye-1 and/or IKONOS Products © GeoEye, distributed by e-GEOS. 38th NORTH BLOG
http://38north.org/2011/11/elwr111411/picture3/


22 May image of reactor
N
crane is putting the pilons in place
dome
water intake facility under construction


05 July image of reactor
look it's a building now!
pilons are up
the steel scaffold looks more complete

Figure 7. The ELWR at Yongbyon as of November 3, 2011. The domed top of the reactor building is now clearly visible (to the right of the building). Image Credit: 38 North/USKI, DigitalGlobe.
http://38north.org/2011/11/elwr111411/dg_dprk_yongbyon_nov03_11_b/ 38th NORTH BLOG

# KEDO 1,000 MWe LWRs




With assistance from KEDO, North Korea began building twin 1,000 MWe LWR's on a site at Sinpho. **The project was 35% complete.** Indigenous knowledge base.

# Prospects for Pilot LWR Future

***Left: 1,000 MWe CPR-1000 PWR Unit 4 at the Hongyanhe nuclear power plant in Liaoning province in northeast China. Construction began August 2009 . Unit 4 to be operational by 2014.***

DPRK ELWR operation likely not for 2 to 3 years

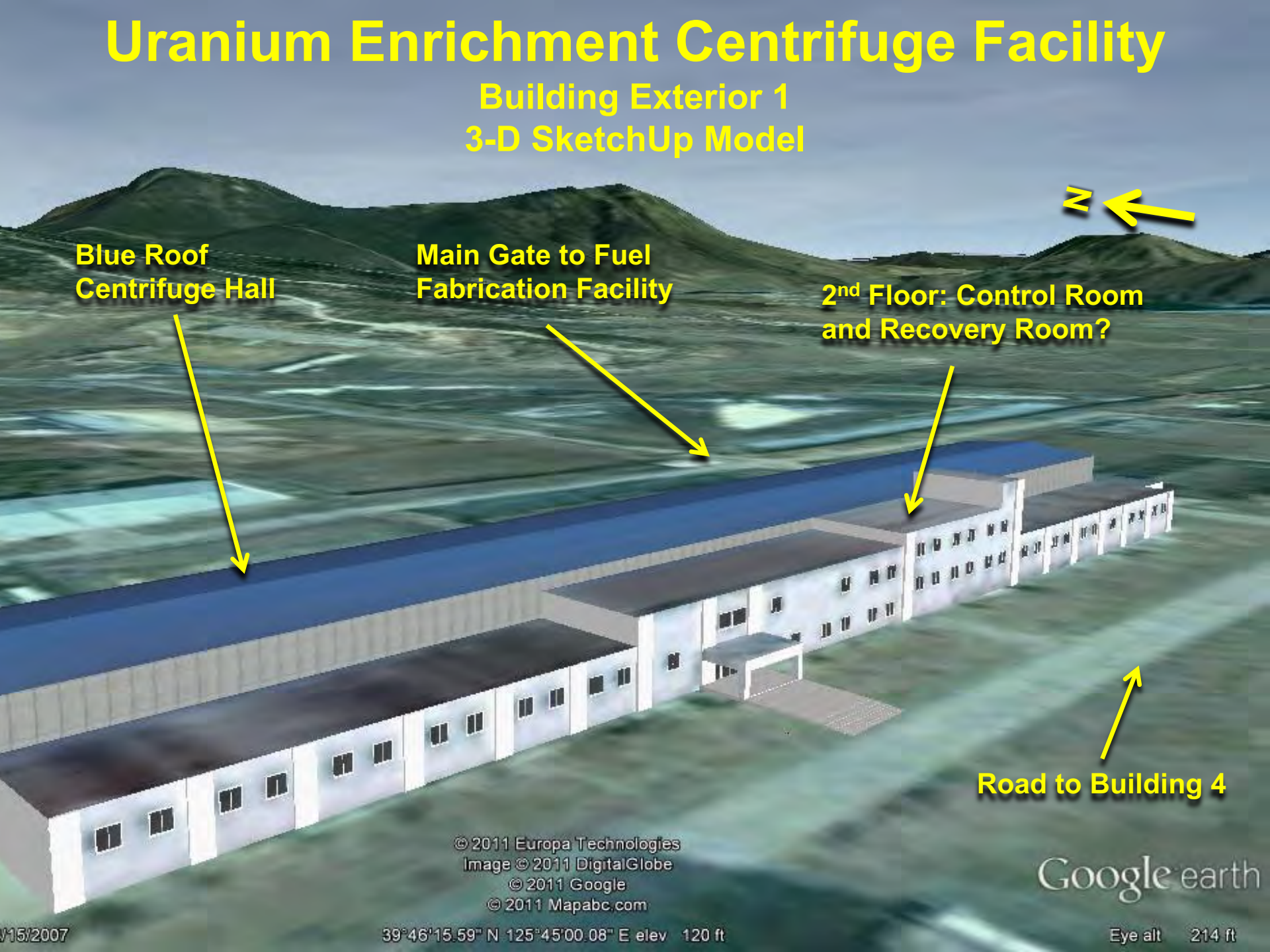
# Agreed Framework: Trade GGRs for LWRs


**KEDO LWR before U.S. abandoned the project - 2003**

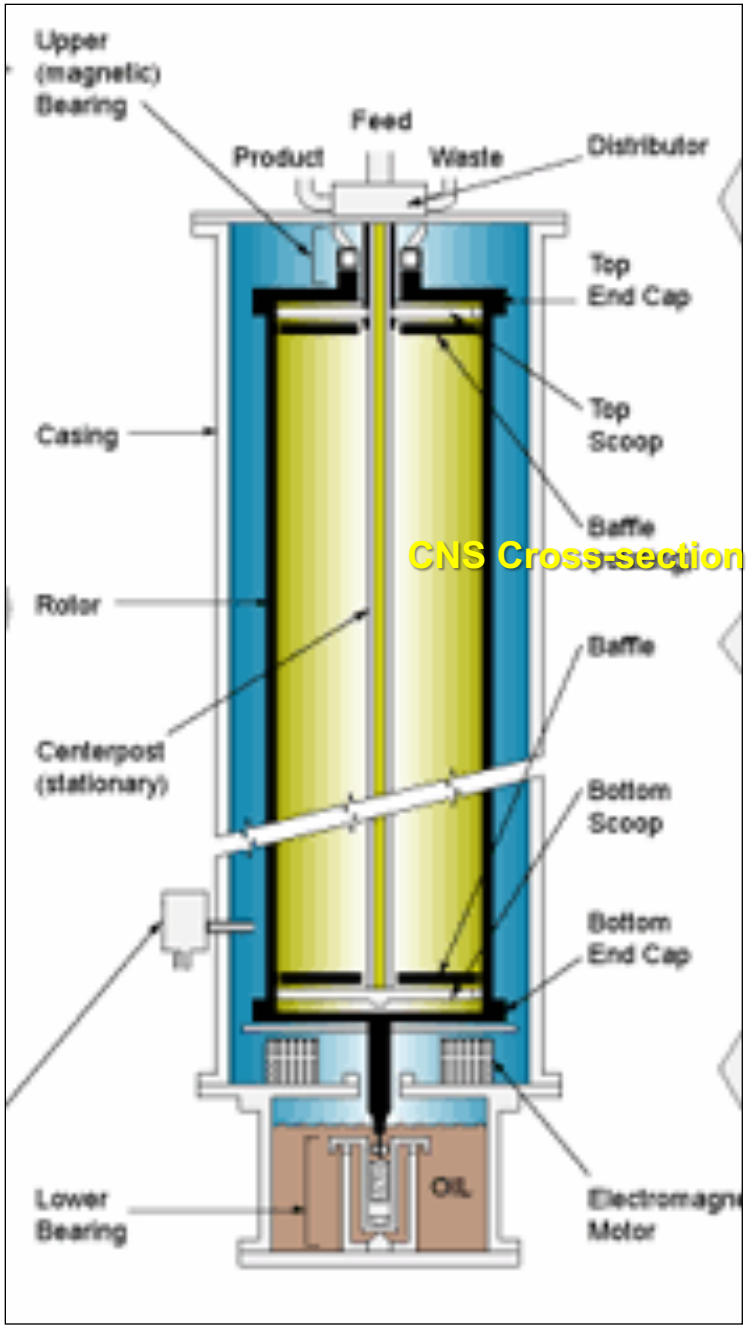
# Yongbyon Fuel Fabrication Plant

# Uranium Enrichment Centrifuge Facility

## Building Exterior 1
## 3-D SketchUp Model




US Example


Upper
(magnetic)
Bearing
Feed
Product
Waste
Distributor
Top
End Cap
Casing
Top
Scoop
Baffle
CNS Cross-section
Rotor
Baffle
Centerpost
(stationary)
Bottom
Scoop
Bottom
End Cap
Lower
Bearing
Oil
Motor

# Cascade Hall, Yongbyon, DPRK

## 3-D SketchUp Model

### West Observation Window

# Syrian reactor site at Dayr az Zawr region bombed by Israel on Sept. 6, 2007

Before bombing

After bombing

# Satellite Photos Show Cleansing of Syrian Site

By WILLIAM J. BROAD and MARK MAZZETTI

Published: October 26, 2007, New York Times

Suspected reactor site in Dayr az Zawr region bombed by Israel on September 6, 2007

Same site in Dayr az Zawr region in October after Syrian cleanup