Nuclear Security: Science and Policy

Siegfried S. Hecker
Center for International Security and Cooperation
Stanford University

Science Policy, National Security, and Cybersecurity
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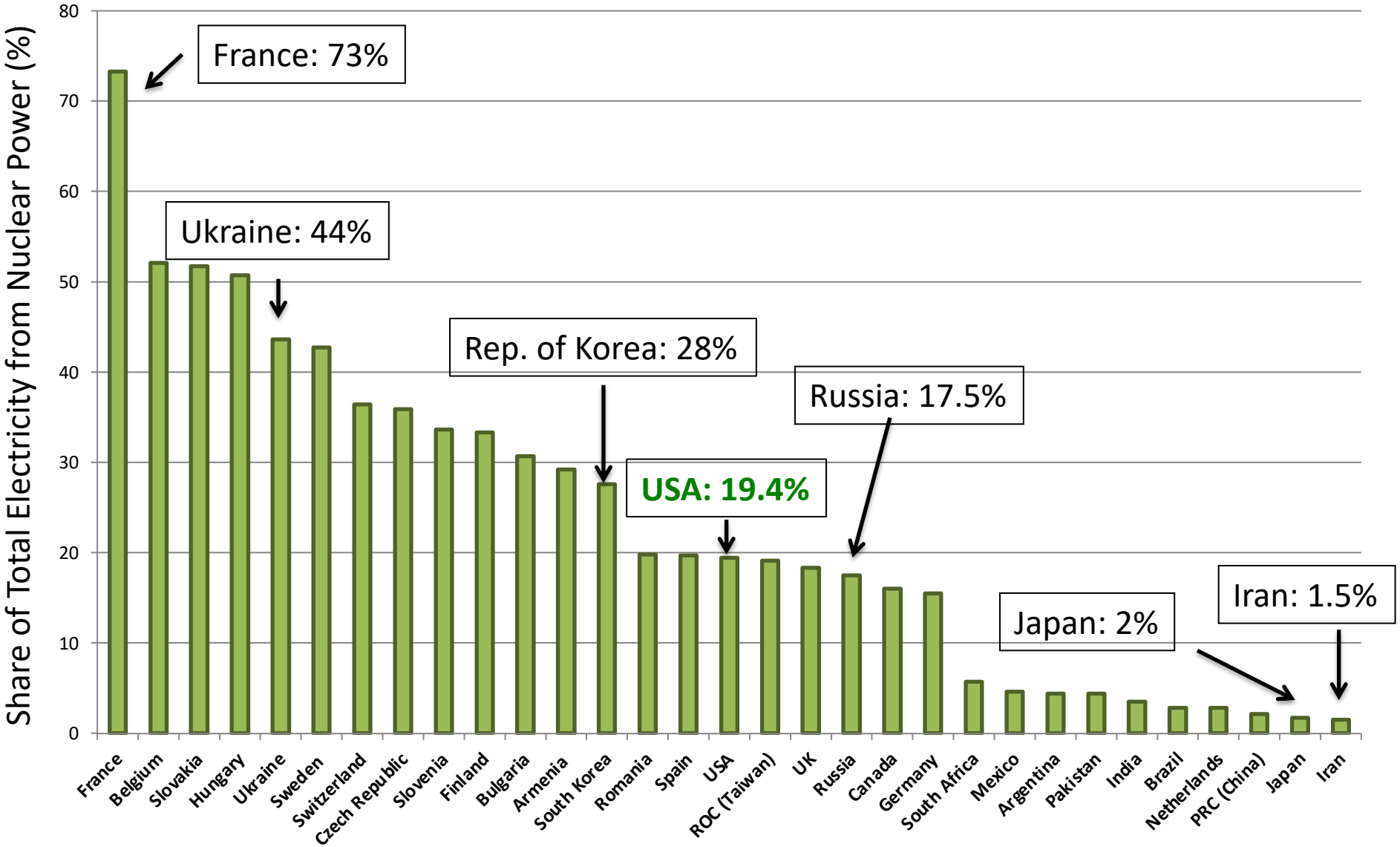
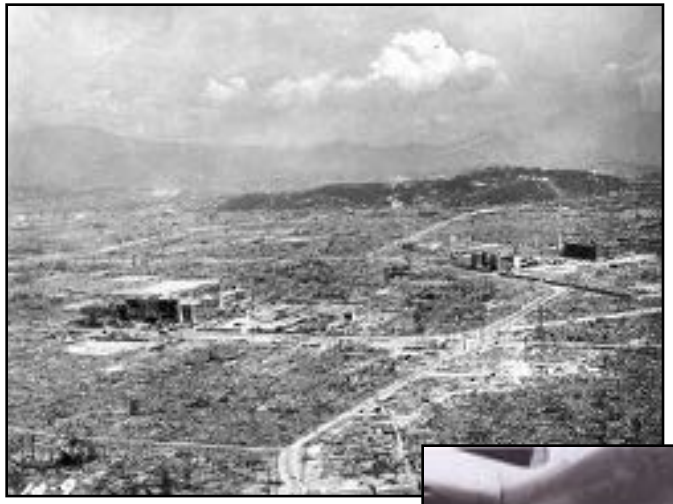
Nuclear energy can electrify the world

Nuclear Share Figures, 2003-2013 - IAEA



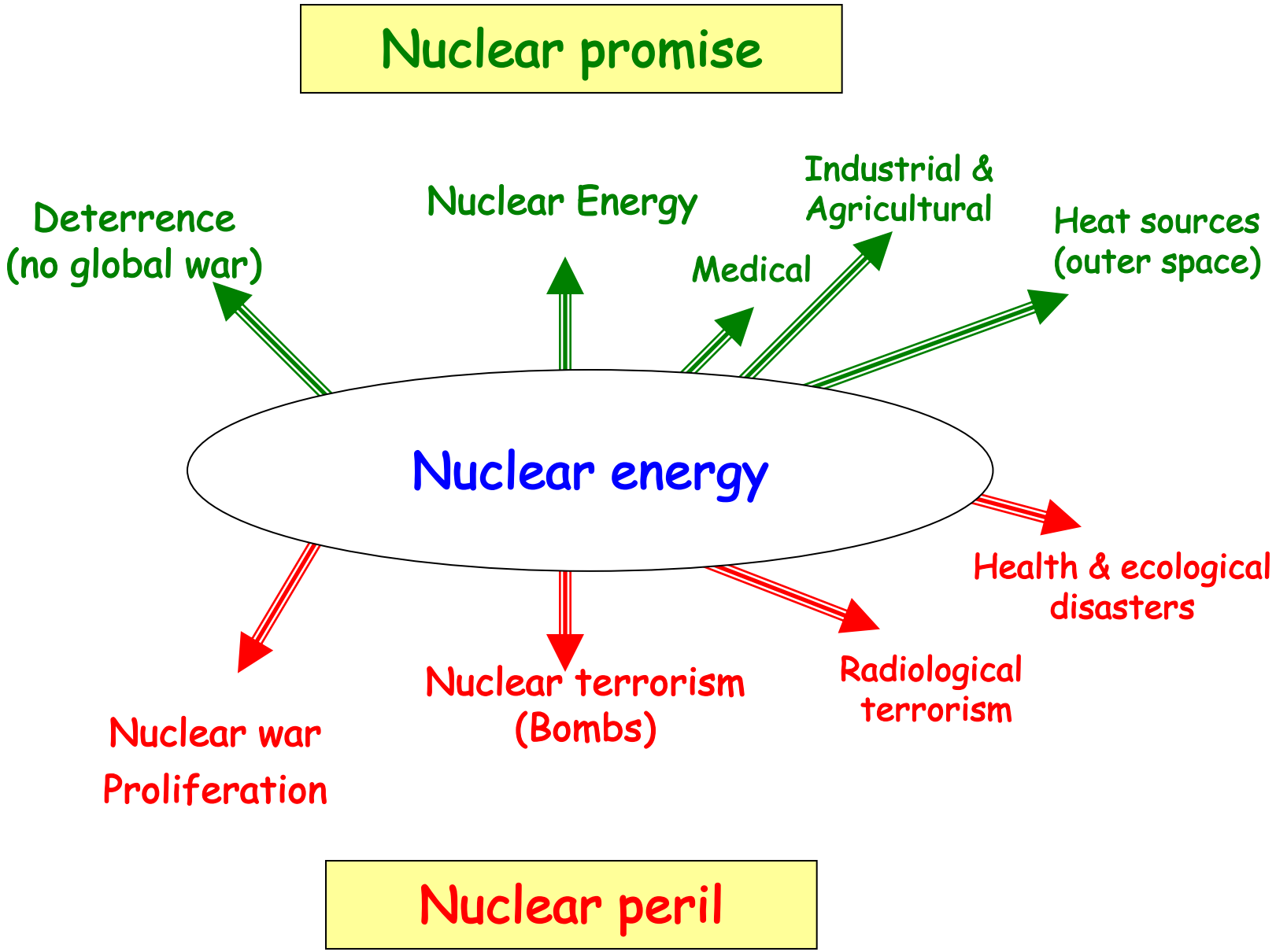

Or, it can destroy the world
Corbis.com

Hiroshima – one bomb, not a campaign



A factor of millions

Hiroshima, August 6, 1945
1 B-29
4.7 sq. miles destroyed
140,000 – 150,000 dead


Nuclear promise
Deterrence
(no global war)
Nuclear Energy
Medical
Industrial &
Agricultural
Heat sources
(outer space)
Nuclear energy
Health & ecological
disasters
Radiological
terrorism
Nuclear terrorism
(Bombs)
Nuclear war
Proliferation
Nuclear peril

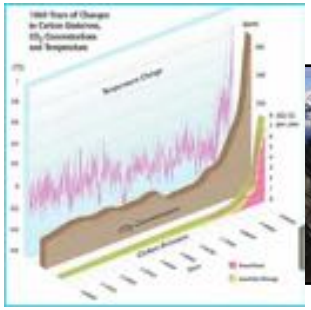
Why we have to get nuclear right

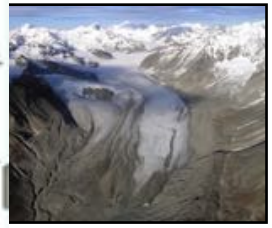
- **Nuclear weapons**
  - **Potential end of life as we know it**

- **Nuclear proliferation and terrorism**
  - **Threat to democracies and way of life**

Cover Credit: MATT MAHURIN

- **Nuclear energy**
  - **To help avoid catastrophic consequences of global climate change and potential disruptions**





- Never before in the history of warfare had there been a continuing explosive…these atomic bombs which science burst upon the world that night were strange even to the men who used them.
- The moral shock of the atomic bombs had been a profound one, and for a while the cunning side of the human animal was overpowered by its sincere realisation of the vital necessity for reconstruction.
- In the map of nearly every country of the world three or four or more red circles, a score of miles in diameter, mark the position of the dying atomic bombs and the death areas that men have been forced to abandon around them. Within these areas perished museums, cathedrals, palaces, libraries, galleries of masterpieces, and a vast accumulation of human achievement, whose charred remains lie buried, a legacy of curious material that only future generations may hope to examine....

H.G. Wells – 1914

- Never before in the history of warfare had there been a continuing explosive…these atomic bombs which science burst upon the world that night were strange even to the men who used them.
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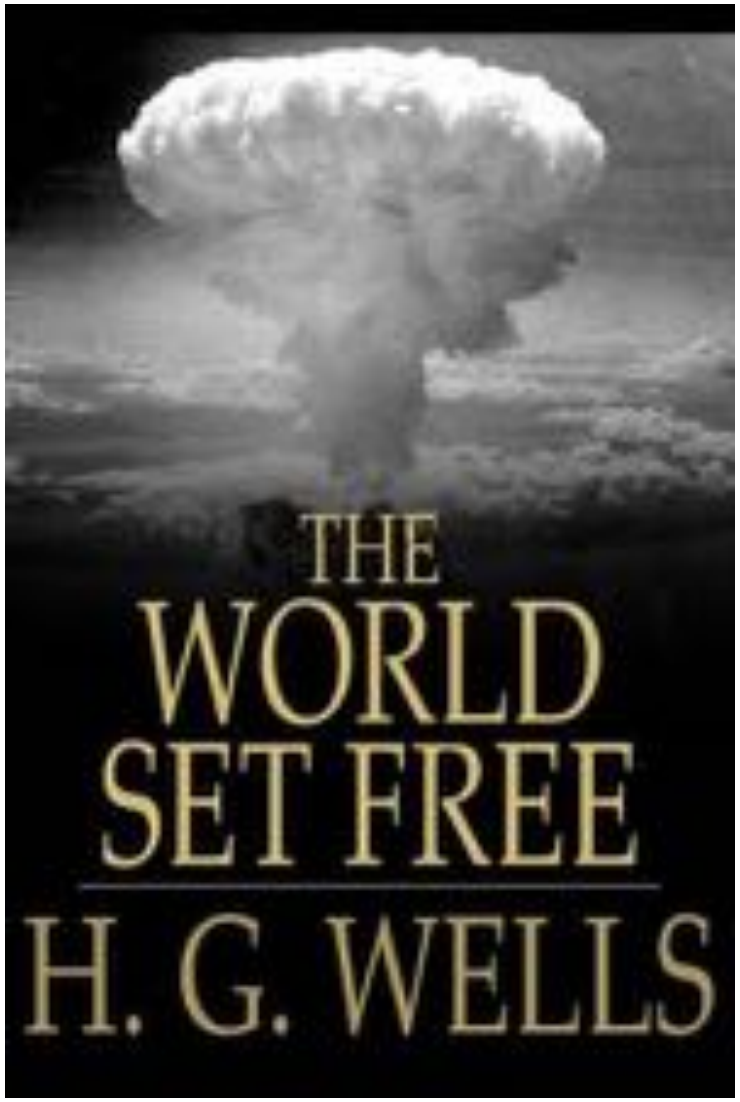
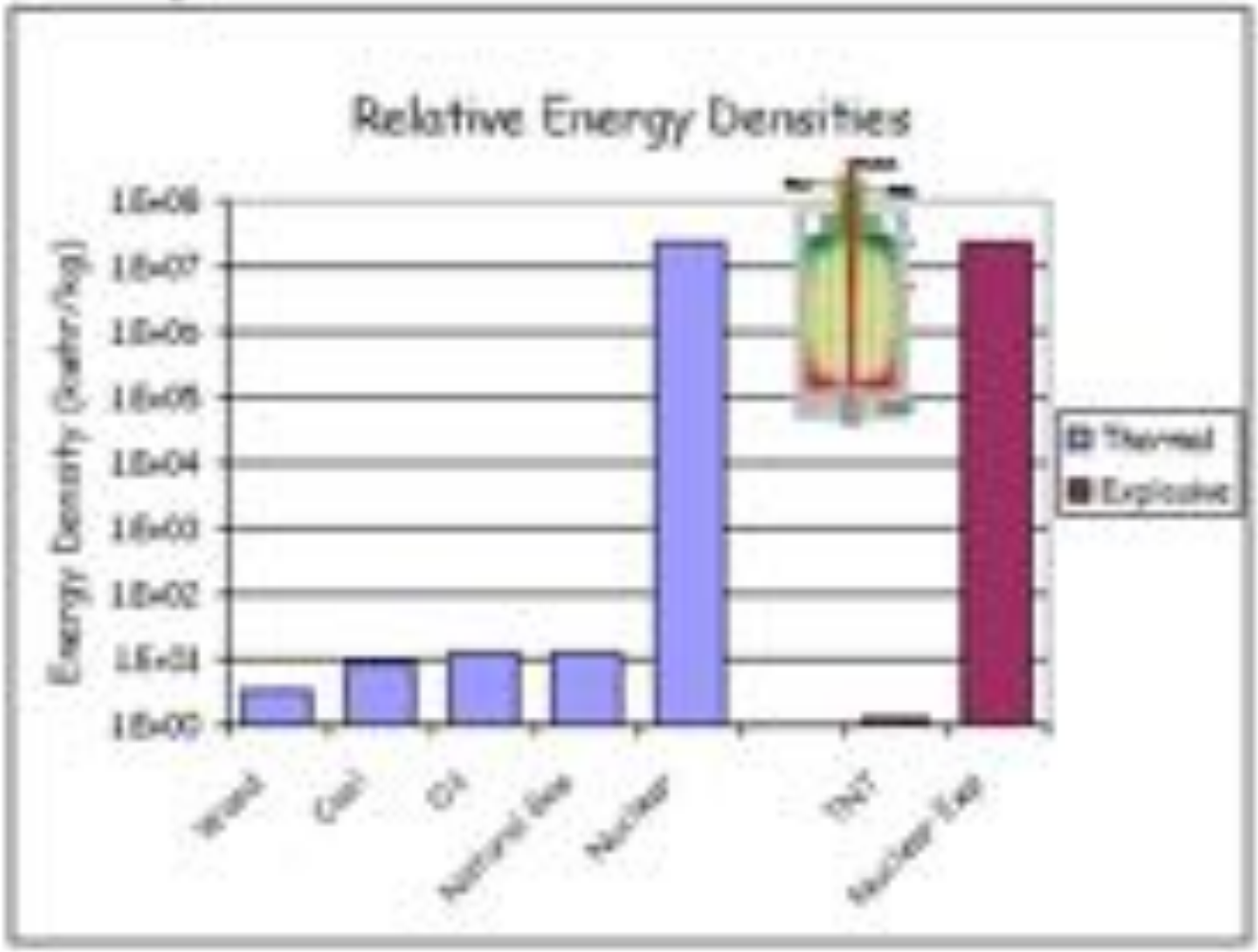


Why Nuclear?


Relative Energy Densities
Energy Density (watt-hr/kg)
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
1E+02
1E+01
1E+00
Thermal
Explosive

Nuclear power has supplied 15% of the world's electricity…

… but it is concentrated heavily in the developed world.

Major expansion will come in the developing world – China & India

Fuel consumption and waste generation from various electricity generation sources for 1GWe.year

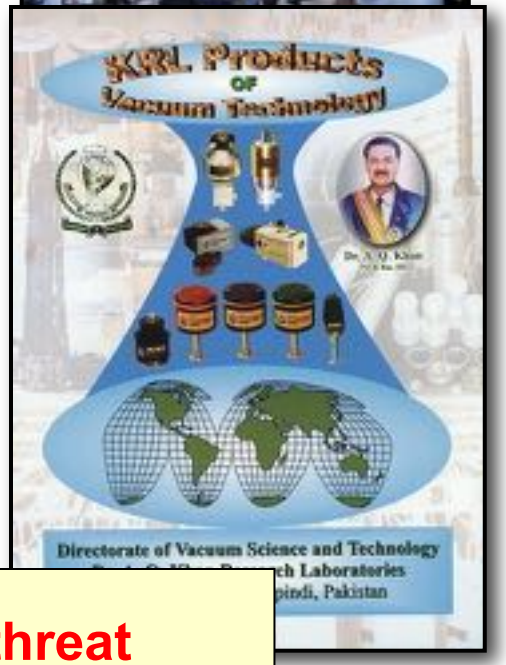
	Fuel consumption [ton]	Waste generation [ton]	
Crude oil	1,400,000	CO2	5,000,000
		SO2	40,000
		NOx	25,000
		dust, particles, ashes	25,000
Coal	2,200,000	CO2	6,000,000
		SO2	120,000
		NOx	25,000
		dust, particles, ashes	300,000
LNG	1,000,000	CO2	3,000,000
		SO2	20
		NOx	13,000
Nuclear	30	(Uranium)	(28.8)
		(Plutonium)	(0.3)
		Fission products	0.9

Nuclear peril – Fukushima Daiichi

World War II & Cold War

Catastrophic terrorism, Nuclear proliferation

Breakup of the Soviet Union
Russia in transition



Evolution of the nuclear threat

Early warnings about the inevitability of proliferation

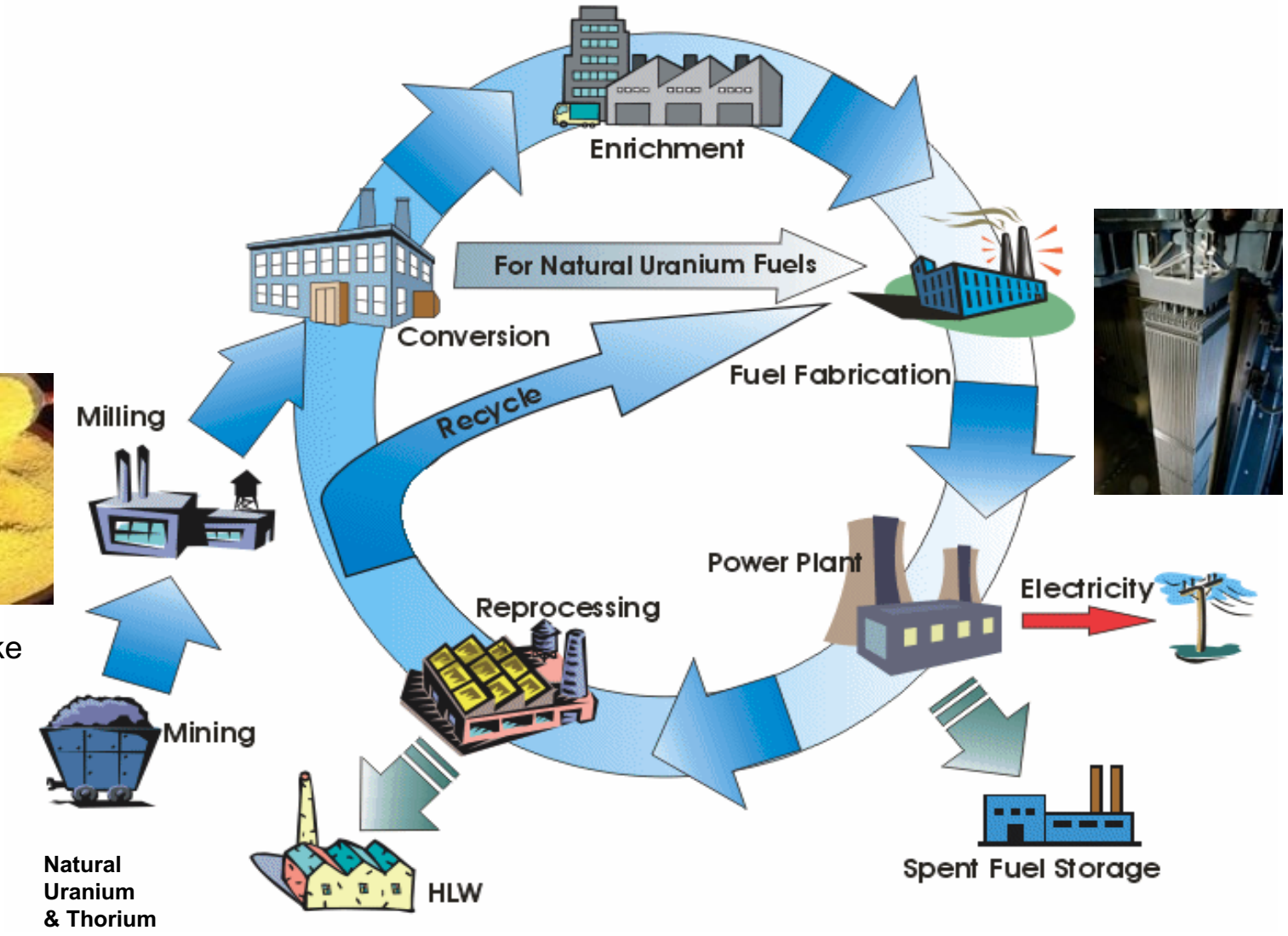
"A Report on the International Control of Atomic Energy". Acheson-Lilienthal Report, March 28, 1946

• It is further recognized that atomic energy plays so vital a part in contributing to the military power, to the possible economic welfare, and no doubt to the security of a nation, that the incentive to other nations to press their own developments is overwhelming.

• The development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their course interchangeable and interdependent.

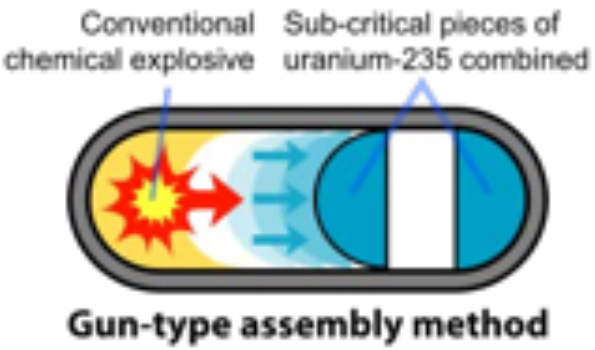
Dual-use dilemma of the nuclear fuel cycle

U_3O_8 or Yellowcake



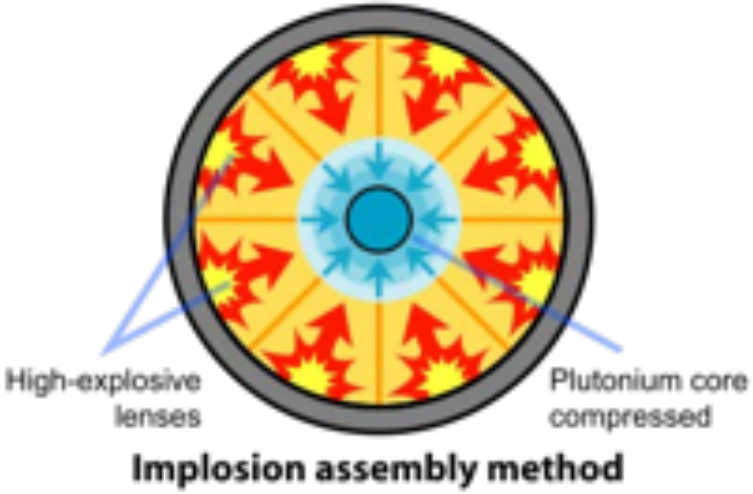
Two paths to the bomb

- **Uranium-235 (Produced by enrichment)**
- Natural uranium is 99.3% U-238 and 0.7% U-235
- >20% HEU is weapons usable
- A few tens of kg of 90% U-235 required for a bomb



Hiroshima – Aug. 6, 1945

- **Plutonium-239 (Produced in reactors)**
- Pu-239 metal, typically >93% Pu-239 for bombs
- < 10 kg required for a bomb



Trinity – July 16, 1945
Nagasaki – Aug. 9, 1945

Little Boy and Fat Man

Cold War – Mutually Assured Destruction

“Tsar Bomba” tested at half yield (~ 50 Megatons) Oct. 30, 1961

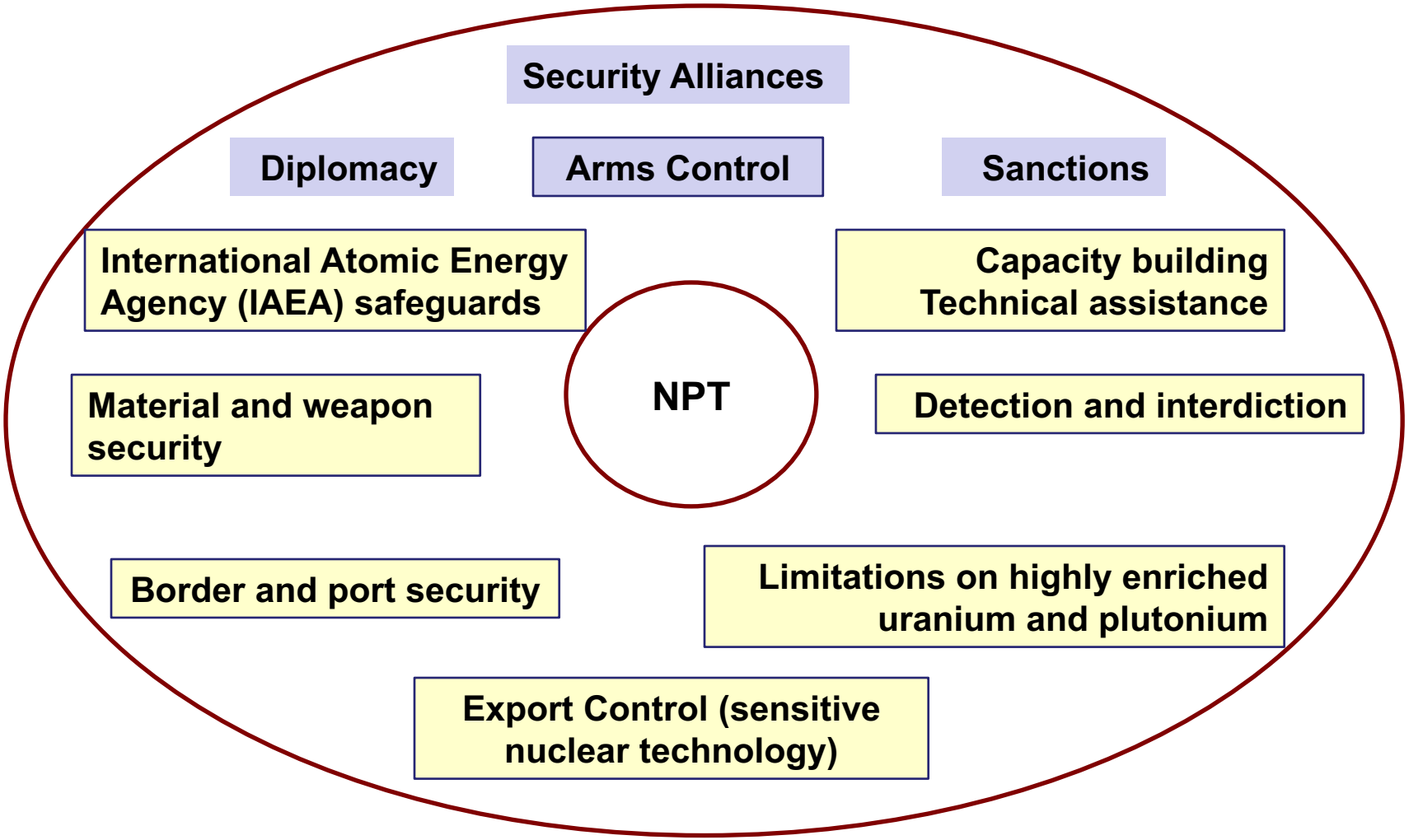
Cuban Missile Crisis – Oct. 1962

The goal of the Nuclear Nonproliferation Treaty (NPT) is to limit the spread of nuclear weapons.

Nuclear Weapon States (NWS)	Non-Nuclear Weapon States (NNWS)
Commit not to assist other states to acquire or develop nuclear weapons	**Commit not to develop or acquire nuclear weapons and to implement IAEA safeguards**
All agree not to export nuclear equipment or material to NNWS except under safeguards	
All agree to facilitate exchange of peaceful nuclear technology	
All agree to work towards future nuclear (and total) disarmament	

Three pillars – nonproliferation, right to energy, disarmament

The nuclear nonproliferation system includes a range of multilateral and bilateral measures



Countries that have considered the bomb

- Sweden
- Switzerland
- Israel
- Yugoslavia
- India
- Pakistan
- South Korea
- North Korea
- Japan
- Taiwan
- Argentina
- Brazil
- South Africa
- Iraq
- Libya
- Iran

Besides the P-5

- U.S. - 1945
- USSR - 1949
- UK - 1952
- France 1960
- China 1964

Iran and North Korea

North Korea threatened nuke strikes on US, South Korea

By FOSTER KLUG
Mar. 7, 2016 5:24 AM EST

SEOUL, South Korea (AP) — North Korea on Monday issued its latest belligerent threat, warning of an indiscriminate "pre-emptive nuclear strike of justice" on Washington and Seoul, this time in reaction to the start of huge U.S.-South Korean military drills.


Can Kim Jong-un nuke the U.S.?

Will the Iran deal hold?

What does history tell us?

- 1950s - 60s: U.S. “Atoms for Peace”
- 1970s to 1979: Grand nuclear power plans and covert bomb ambitions (with Israel, South Africa)
- Ayatollahs abandon, then go covert in mid-1980s
- 1990s: Iran goes shopping, steps up covert program
- 2002 – 12: Program discovered and admitted. Lack of transparency and inadequate cooperation with IAEA leads to suspicion of military program
- 2013 – H. Rouhani elected. Shows new flexibility.
- 2014 & 2015 Framework Agreement – and deal

How close was Iran to the bomb before the JCPOA?

•Demonstrated uranium enrichment
•Adequate capacity for bombs

• Potential for Pu production at Arak but need reprocessing

HEU only weeks to months away once decision is made

•Physics/computation
•High explosives
•Detonators
•Initiators
•Machining
•Assembly
•Need explosives tests or help for Pu

Likely ready by 2003
Had not allowed IAEA inspections of suspect sites

•Truck/van
•Plane
•Boat
•Missile

Vigorous Missile Program

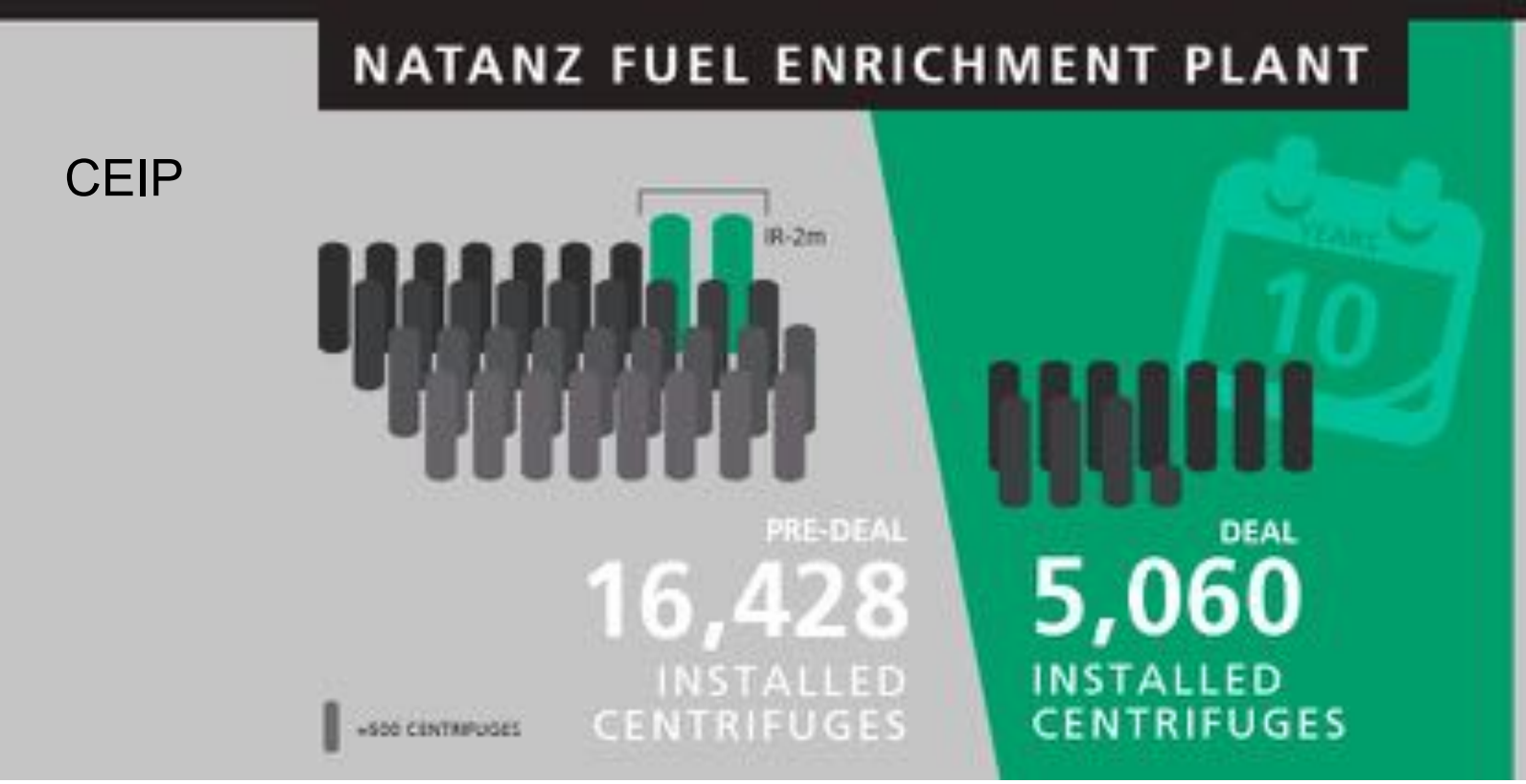
Before the JCPOA Iran likely had all pieces in place for the nuclear weapon option.

Iran's Key Nuclear Facilities

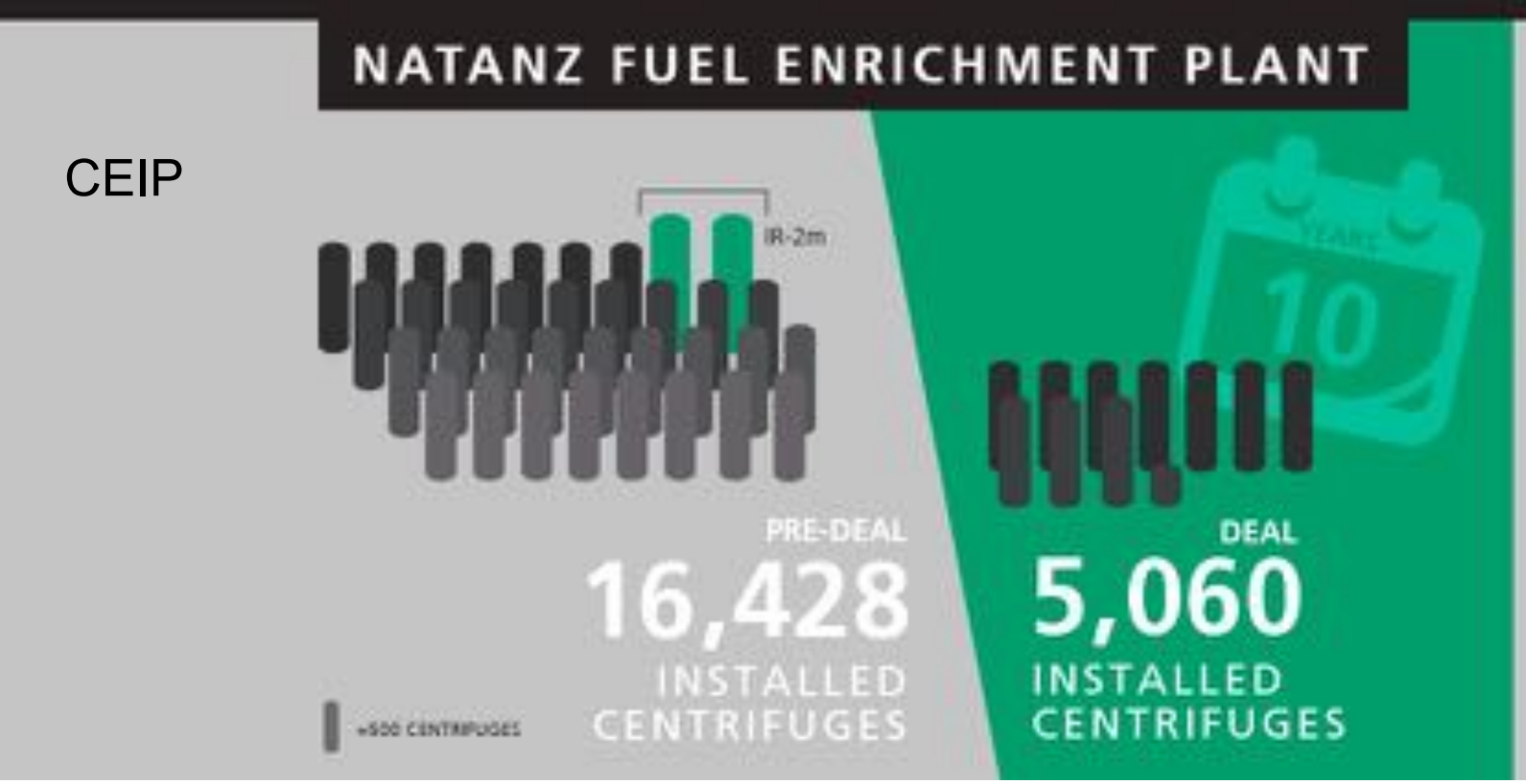
Arms Control Association

FACILITY NAME	STATUS	FUNCTION
Fuel Enrichment Plant, Natanz	OPERATING, INCOMPLETE	Produces 3.5 percent-enriched uranium
Pilot Fuel Enrichment Plant, Natanz	OPERATING	Research, development, test, and evaluation on advanced centrifuges; produces 20 percent-enriched uranium
Fordow Fuel Enrichment Plant	OPERATING, INCOMPLETE	Produces 20 percent-enriched and 3.5 percent-enriched uranium
Tehran Research Reactor	OPERATING	Produces medical isotopes
Heavy-Water Reactor (IR-40), Arak	UNDER CONSTRUCTION	Produces medical isotopes; better suited to producing plutonium
Uranium Conversion Facility, Esfahan	SUSPENDED	Produces uranium hexafluoride, the feedstock for uranium enrichment
Fuel Manufacturing Plant, Esfahan	PARTIAL OPERATION	Produces fuel assemblies for reactors; can possibly fashion uranium metal cores for nuclear weapons
Bushehr Nuclear Power Plant, Bushehr	OPERATING	Produces electricity; has limited proliferation risk
Ardakan Yellowcake Production Plant, Ardakan	OPERATING	Processes mined uranium

CEIP


NATANZ FUEL ENRICHMENT PLANT
IR-2m
PRE-DEAL
16,428
INSTALLED
CENTRIFUGES
DEAL
5,060
INSTALLED
CENTRIFUGES

CEIP



Reduce by ~2/3 installed centrifuges

19,000 today to 6,104 installed, IR-1s only

No enrichment over 3.67%

Reduce current stockpile LEU from 10,000kg to 300 kg

Only enrichment of uranium to occur at Natanz facility for 10 years

Removal of advanced centrifuges

Only 5,060 IR-1 centrifuges

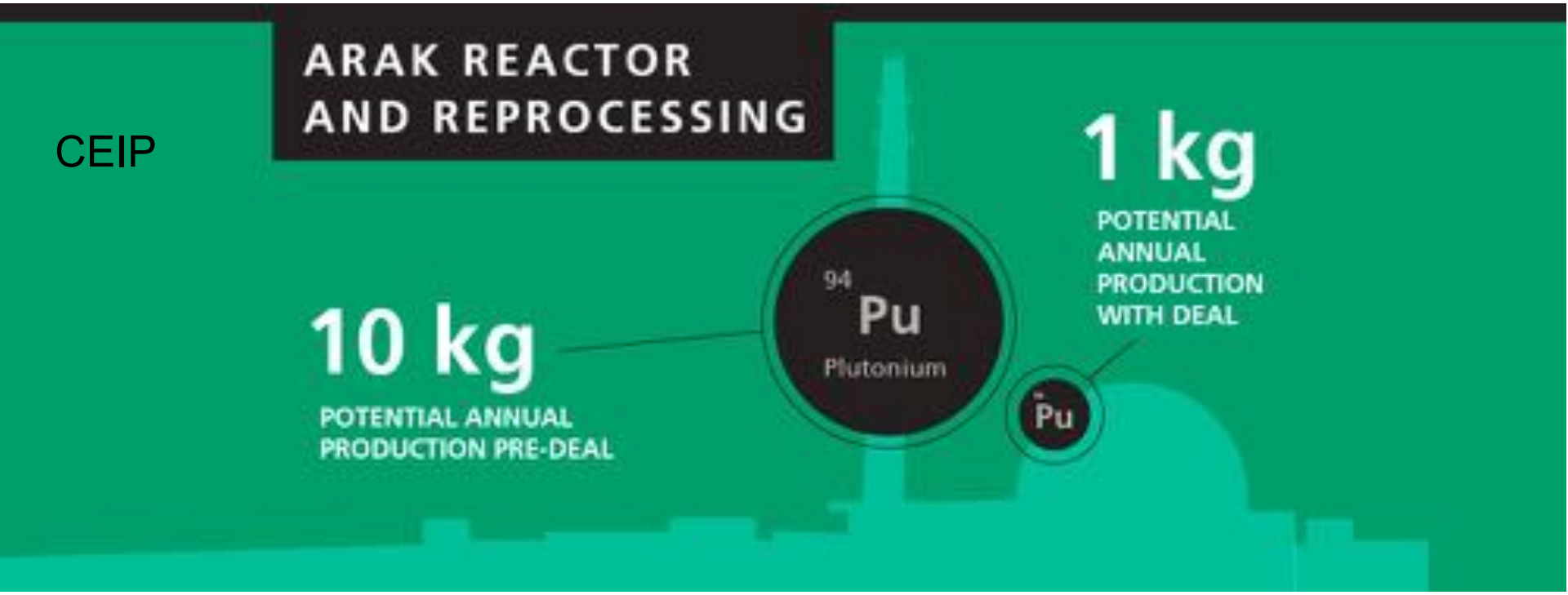
Only limited R&D with advanced centrifuges

CEIP

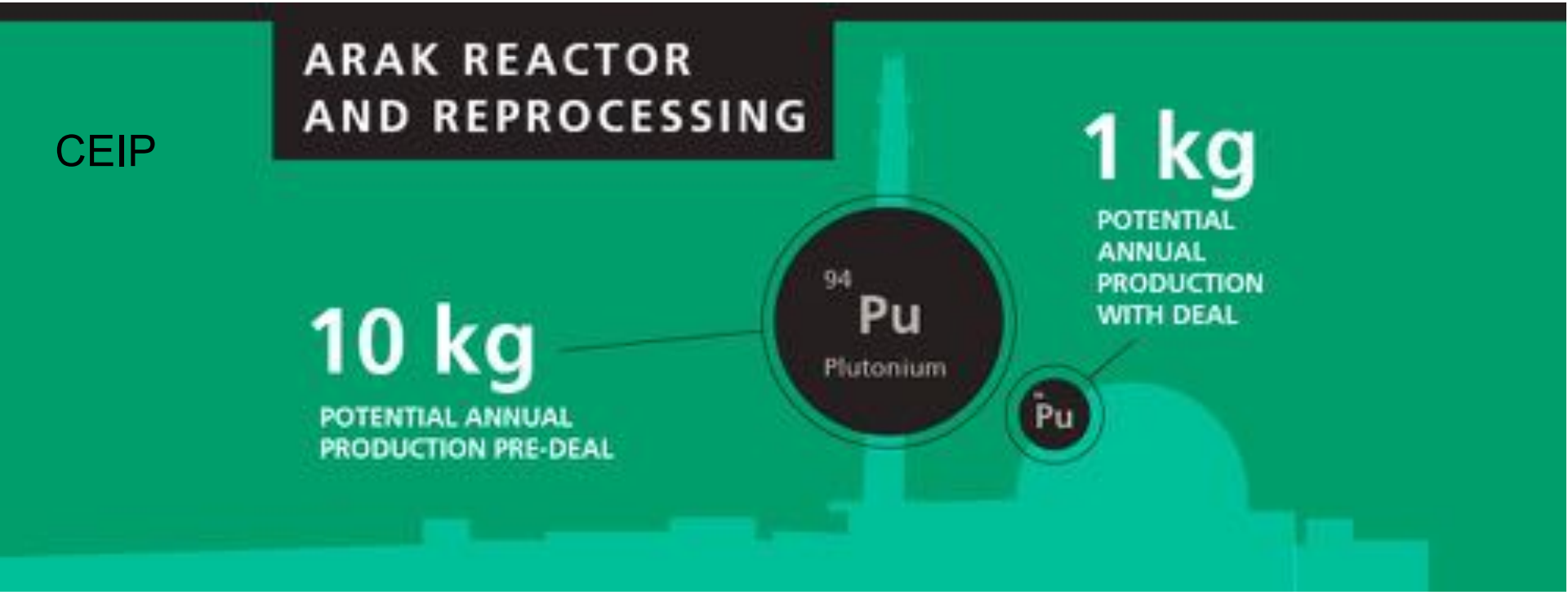

FORDOW SITE
15 YEARS
uranium enrichment
centrifuge R&D
nuclear material

- No enrichment of uranium at Fordow
- Conversion of facility to a nuclear, physics, technology research center
- No uranium enrichment R&D
- No fissile material
- 2/3 of centrifuges and infrastructure to be removed
- All centrifuges and infrastructure under IAEA monitoring

CEIP


ARAK REACTOR
AND REPROCESSING
1 kg
POTENTIAL
ANNUAL
PRODUCTION
WITH DEAL
94
Pu
Plutonium
10 kg
POTENTIAL ANNUAL
PRODUCTION PRE-DEAL
Pu

CEIP



New design and construction of heavy water research reactor
Removal or destruction of original core
Removal of all spent fuel for reactor's lifetime
No further reprocessing/ R&D on spent fuel
No accumulation of heavy water beyond needs of new Arak reactor
No additional HWRs for 15 years

CEIP

IAEA VERIFICATION

- ☑ uranium enrichment
- ☑ centrifuge production and storage
- ☑ uranium mines and mills
- ☑ managed access at suspected secret facilities (including military sites)

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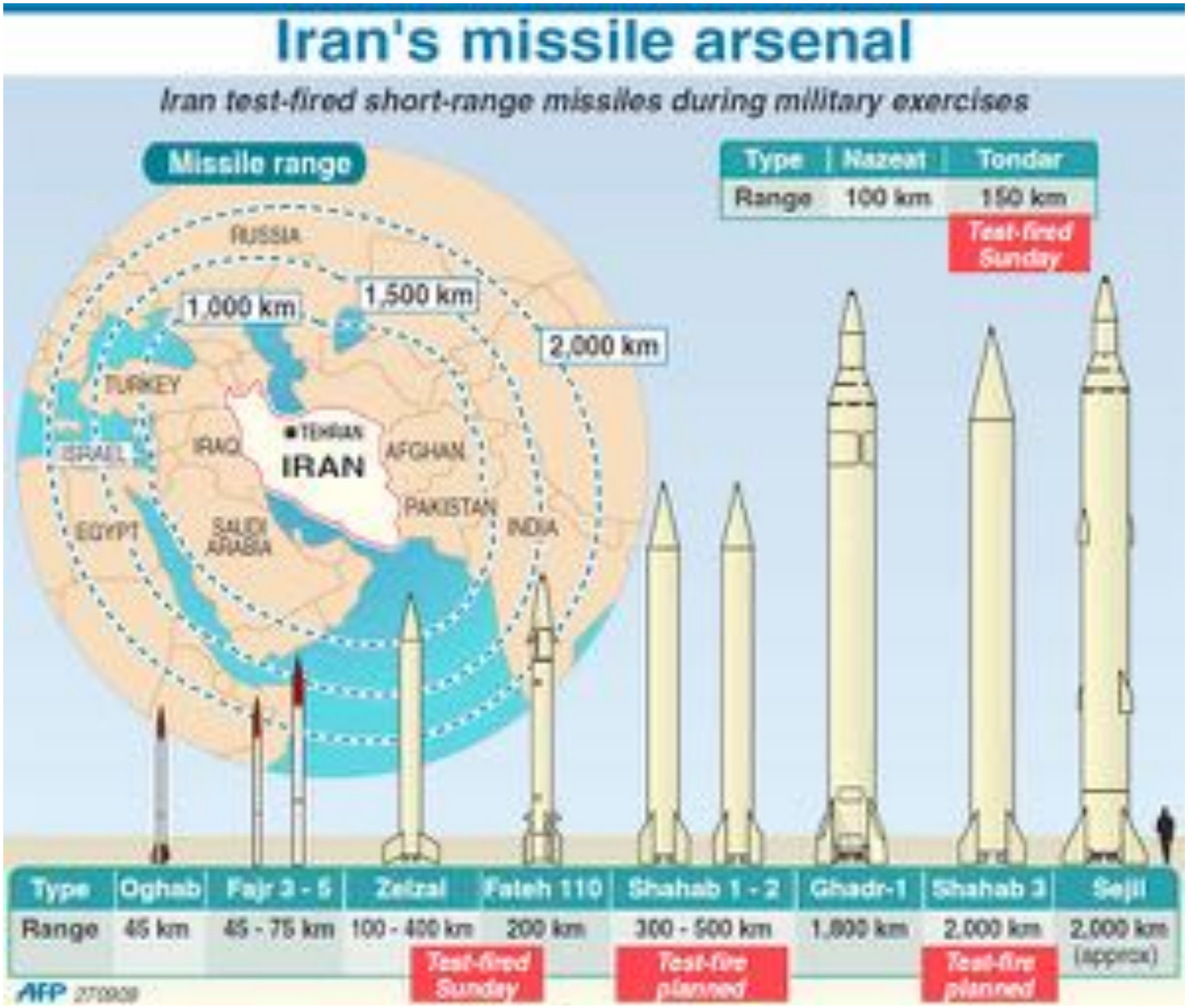
- IAEA regular access to all nuclear facilities with use of advanced monitoring technologies
- Full access to supply chain
- Access to uranium mines and surveillance of uranium mills for 25 years
- Continuous surveillance of centrifuge rotors and bellows production and storage facilities for 20 years
- Freeze of centrifuge manufacturing base
- UN procurement channel for nuclear-related and dual use materials and technology
- Implementation of Additional Protocol
- Early notification of construction of new facilities
- Agreed set of measures regarding Possible Military Dimensions (PMD) of Iran program



Iran missile development is great concern, but not part of deal

Does Iran want nuclear weapons at this time?

North Korea's nuclear history

Kim Il-sung
- Soviet Atoms for Peace
- Indigenous reactor program
- Built the option for the bomb
- Agreed to freeze program in 1994

Kim Jong-il
- Built the bomb in 2003,
- Signed denuclearization deal 2005
- Continued with bomb, tested 2006, 2009

Kim Jong-un
- First successful space launch in 2012
- Third and fourth nuclear tests, 2013 and Jan. 2016
- Nukes in constitution, threatened to nuke US and the South

Brief history of DPRK nuclear development

- 1950s and 60s – Atoms for peace – building foundation
- 1970s and 80s – Going solo. Dual track
  - Electricity and bombs
  - Plutonium (reactors) and HEU (centrifuges)
- 1990s. Bomb option by 1992. Adding to Pu capacity
  - 1994 Agreed Framework

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- 1990s. Bomb option by 1992
  - 1994 Agreed Framework
  - **Late 1990s – hedge with U enrichment (AQ Khan)**
  - **1998 Taepodong long-range rocket test**

- **2003**
  - **U.S. effectively ends AF. DPRK withdraws from NPT**
  - **DPRK builds Pu bomb**

History of DPRK nuclear development (cont.)

- 2006 Nuclear Test # 1 (initial demonstration)
  - Covert development of centrifuge capacity
- 2009 Nuclear Test # 2 (successful demonstration)
- 2010 Revelation of 2000 centrifuge enrichment capacity

Overhead imagery

History of DPRK nuclear development (cont.)

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- **Dec. 2012 Successful Unha 2 Satellite launch**
- **2013 Nuclear Test # 3 (second successful demo)**
  - **Open expansion of centrifuge capacity**
  - **Building a nuclear arsenal**
- **2015 Apparent rapid expansion of HEU capacity**

Overhead imagery

Old-fashioned looking from the inside

Site visits and technical discussions provide invaluable information

Jan. 2004 Yongbyon

Aug. 2005 Pyongyang

Nov. 2006 Pyongyang

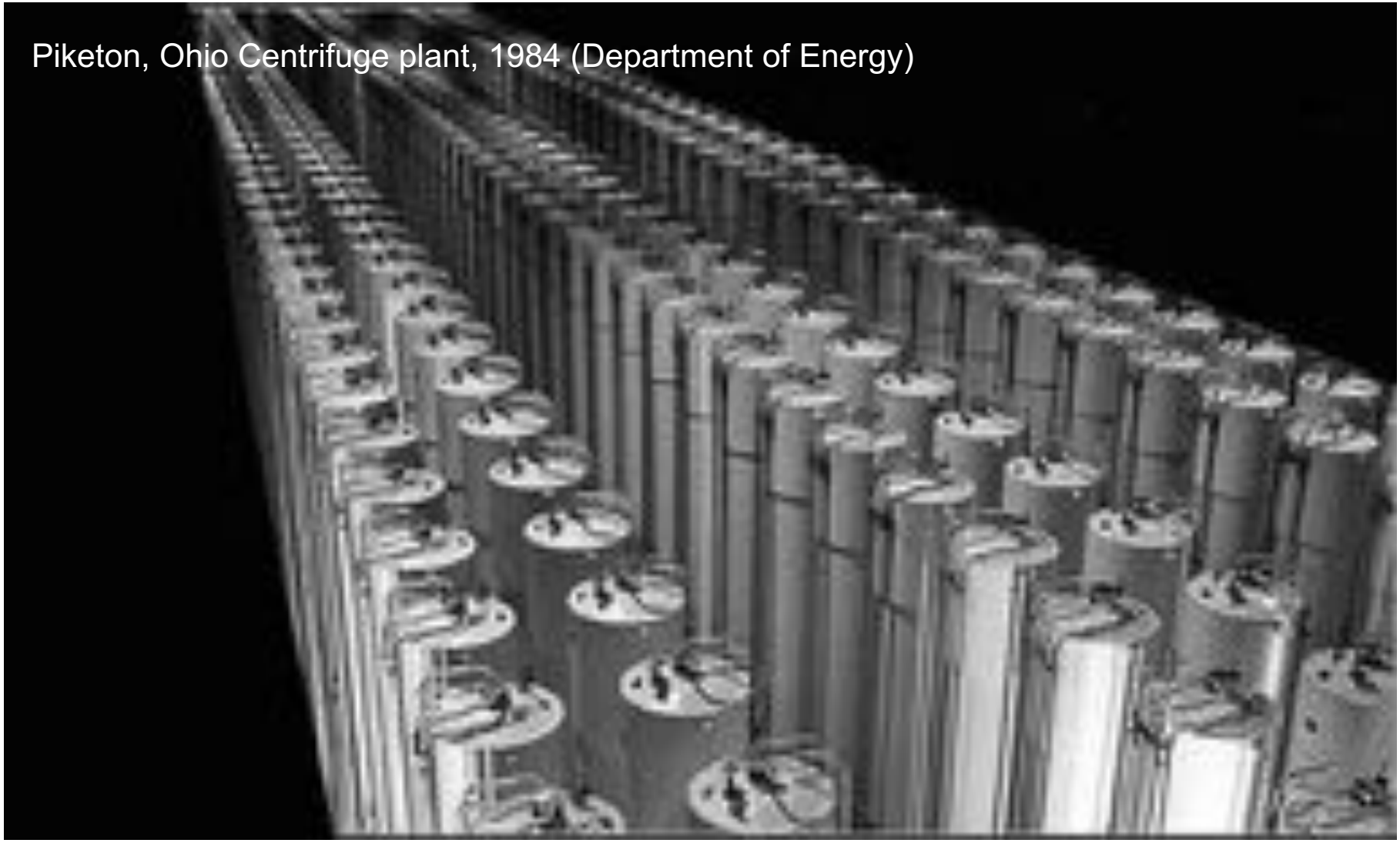
August 9, 2007, Yongbyon

Feb. 14, 2008, Yongbyon

Feb. 27, 2009, Pyongyang

The seventh visit brought a big surprise

Purely illustrative - this is not Yongbyon, but close to what we saw (Nov. 12, 2010).



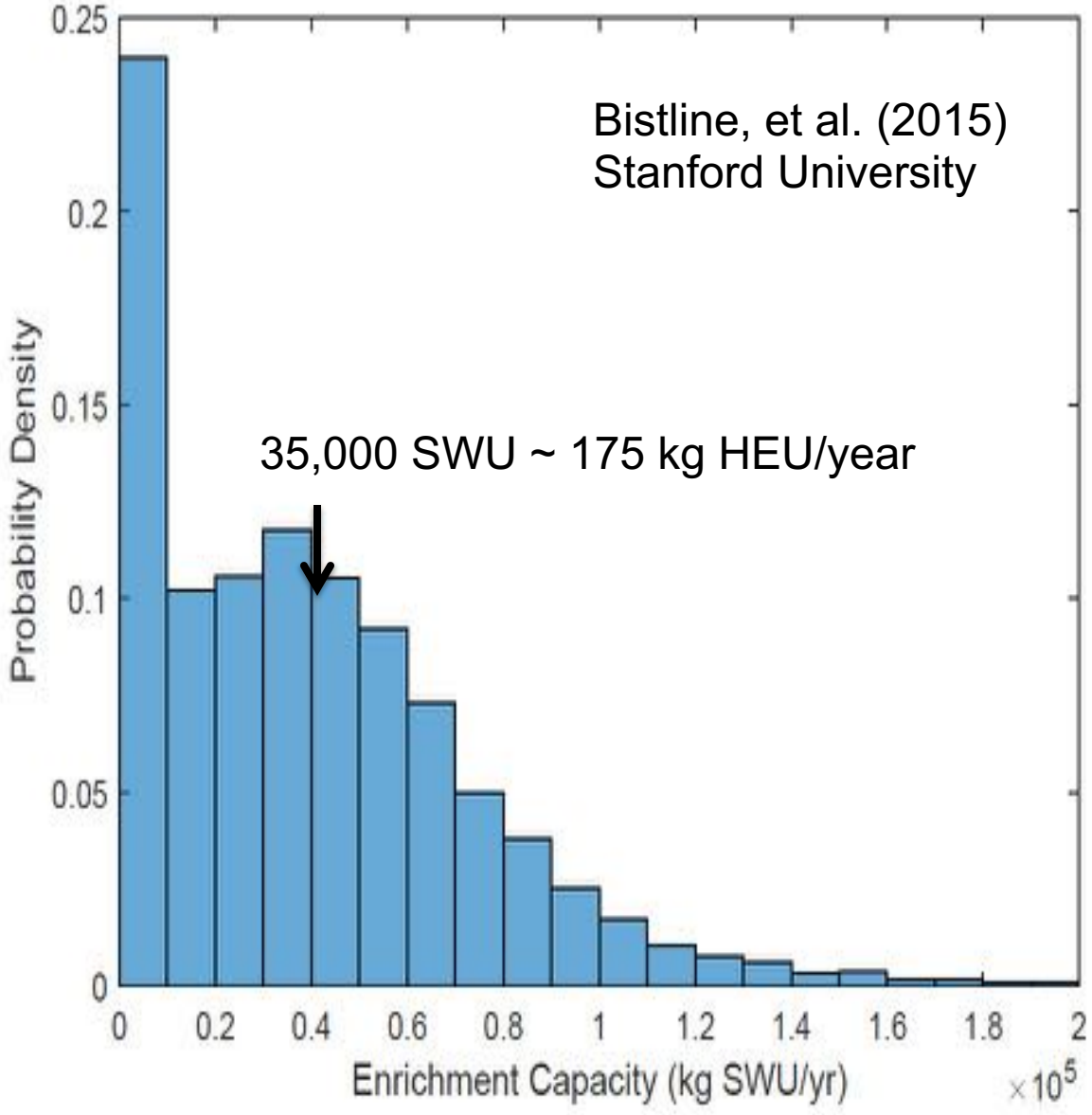
A few thousand are sufficient for bomb fuel. Tens of thousands are required to fuel a commercial power reactor.


What is current centrifuge capacity?
How much imported and how much indigenous?

DPRK nuclear program

Nuclear Capability	January 2003
Nuclear reactors	5 MWe – standby 50 MWe – standby 200 MWe - abandoned
Fuel fabrication	Standby – corroding U conversion - operating
Uranium enrichment	DPRK – denied US – Oct. 2002 accusation
Nuclear export	UF6 to Libya Reactor to Syria
Political	Kim Jong-il No mention of nukes

Plutonium production halted. Uranium enrichment – building capacity.
No nuclear weapons, no successful long-range rockets.



A Bayesian Model to Assess the Size of North Korea's Uranium Enrichment Program
John Bistline, David Blum, Chris Rinaldi, Gabriel Shields-Estrada, Siegfried Hecker, Elisabeth Paté-Cornell, *Journal of Science and Global Security* (2015)

Potential DPRK nuclear program by 2020

Nuclear Capability	December 2016 Estimates	2020
Plutonium	34 – 52 kg	Possibly 70 kg
HEU (Highly enriched U)	Possibly 450 kg	~150 kg/yr
Nuclear tests	4 or more	4 or more
Nuclear weapons	Possibly 8 Pu + 18 HEU **~ 25**	~10 Pu + 42 HEU **~ 50**
Long-range rockets	Unha-3 Possibly more tests	Musudan or KN-08 tests

North Korean nukes

Was it a “hydrogen” bomb?


Warhead in RV?

Rough estimates of nuclear program in North Korea

Laying the foundation

Getting ready

Freeze plutonium program,
but keep a hedge

Challenged and break-out
Built the bomb

Full speed ahead
Building an arsenal

Rough estimates of number of bombs in North Korea

None

None

Likely none

Likely none at start
Possibly 6 at end

Likely 6 at start
Possibly 15 now
Possibly 20-25 by end

Rough estimates of number of bombs in North Korea

Likely none

Likely none

Likely none at beginning
Likely 8 at end

Likely 8 at beginning
Possibly 50 at end

What are the prospects for North Korea?

- **Little hope of giving up nukes in the near term**
- **Must stop nuclear build up first**
- **Settle for 3 No's in return for 3 Yes's**
  - No more bombs
  - No better bombs (no nuclear or missile testing)
  - No export

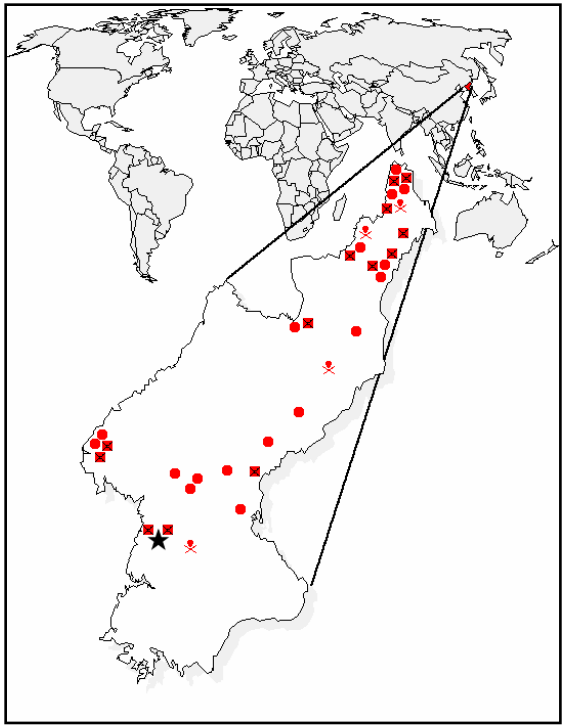
  In return
  - Address the North's security concerns
  - Provide energy assistance
  - Provide economic assistance

Denuclearization will take patience and commitment
And, understanding the country.

North Korea: Repressive and reclusive

DMZ

Human rights concerns



- 4 death camps
- 17 forced labor concentration camps. 13 torture facility prisons

http://www.hrw.org/world-report/2014/country-chapters/north-korea


They are real people
Don't demonize the people

Instructions, discipline and friendship in Middle School #1


University for Foreign Studies
Pyongyang, Feb. 15, 2008

They are very talented people

92nd anniversary of Polish independence
Pyongyang, Nov. 11, 2010

Don't wait for North Korea to collapse

New Pongyang Airport

Ryugyong Hotel


Pyongyang - 2016

Sanctions – ineffective to date

Winds of change are blowing in DPRK

Cell phones in Nov. 2010

The winds of change are not on their side

Pyongyang subway

Where there is swoosh, there is hope