The Iran nuclear deal
Scientific and policy aspects

Frederick K. Lamb

Research Professor of Physics
Core Faculty Member, Program in Arms Control and Domestic and International Security
Professor of Physics and Astronomy Emeritus
Fortner Endowed Chair in Theoretical Astrophysics Emeritus
University of Illinois at Urbana-Champaign

Physics Colloquium
February 3, 2016

The Iran nuclear deal
Scientific and policy aspects

Credit: U.S. Department of State

The Iran nuclear deal
Scientific and policy aspects

The physics and technology of nuclear weapons

The context and history of Iran’s nuclear program

History and provisions of the Iran nuclear deal

The methods being used to verify the Iran deal

The current status of the deal and the prospects that it will prevent Iran from obtaining a nuclear weapon

The explosive power of nuclear weapons

How does the explosive power of a given mass of nuclear-explosive material compare with the explosive power of an equal mass of conventional high explosives?

Credit: AEC

A. About the same

B. 10 times more

C. 100 times more

D. 10,000 times more

E. 1,000,000 times more

The explosive power of nuclear weapons

How does the explosive power of a given mass of nuclear-explosive material compare with the explosive power of an equal mass of conventional high explosives?

Credit: AEC

A. About the same

B. 10 times more

C. 100 times more

D. 10,000 times more

E. **1,000,000 times more**

The destructive effects of nuclear weapons

A nuclear weapon is the only weapon that could destroy a major city and kill hundreds of thousands or millions of people in an instant

Nuclear weapons are the only weapons that could destroy Israel as a functioning society

Nothing can be done ahead of time or afterward to significantly reduce the death and destruction caused by a nuclear explosion

1968 Nuclear Nonproliferation Treaty (NPT) Has 4 basic provisions

- The 5 nuclear-weapon states (NWS; China, France, Russia, UK, US) must cease the nuclear arms race and give up their nuclear weapons.
- The NWS must not give nuclear weapons to non-nuclear weapon states (non-NWS) or help them develop nuclear weapons.
- Non-NWS must not accept or manufacture nuclear weapons.
- In return, non-NWS are guaranteed access to peaceful nuclear technology, including uranium enrichment and plutonium production technology.

The mass of nuclear explosive materials needed to make a nuclear weapon

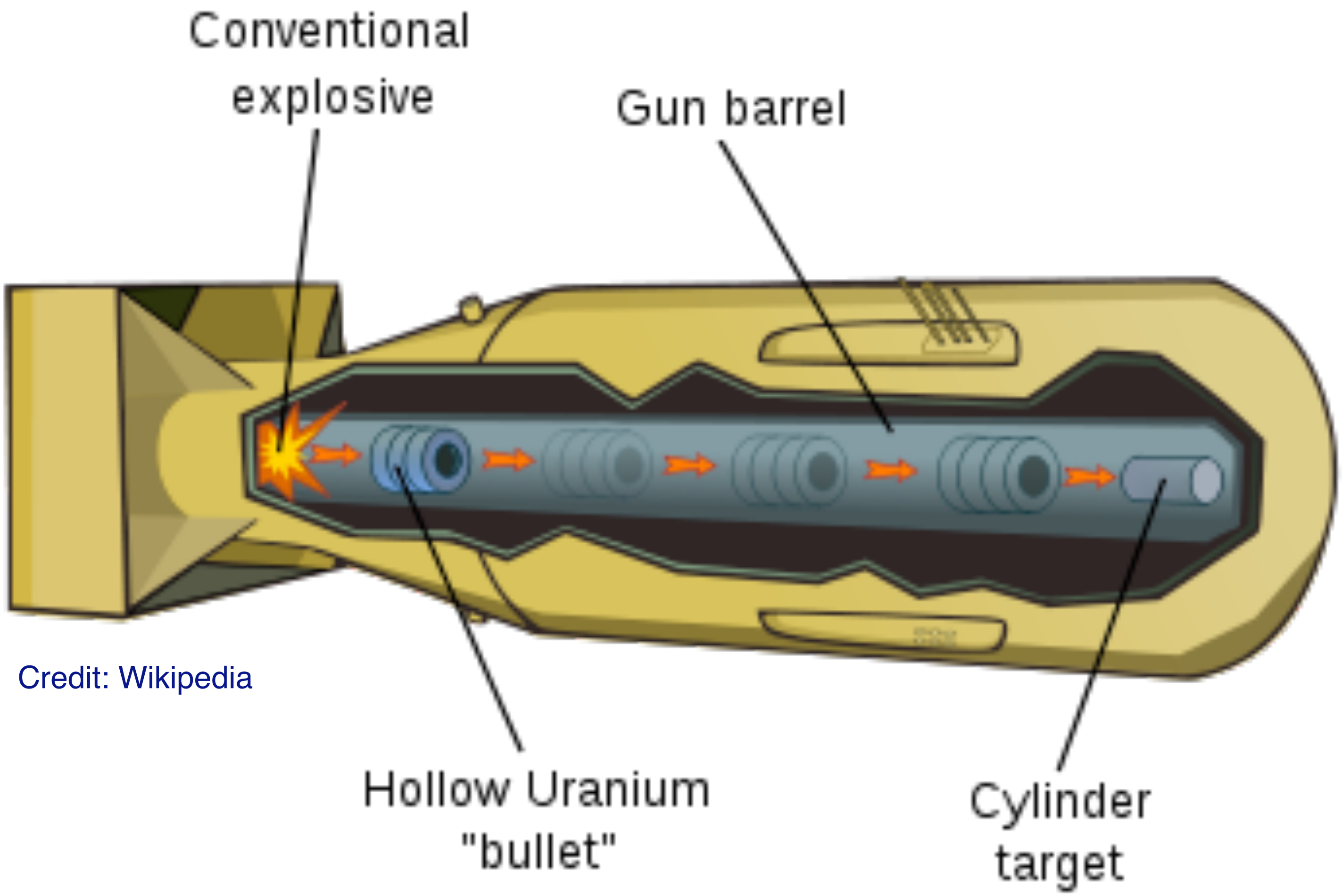
6 kg of weapon-grade Pu

(about the size of a baseball)

15 kg of weapon-grade U

(about the size of a softball)

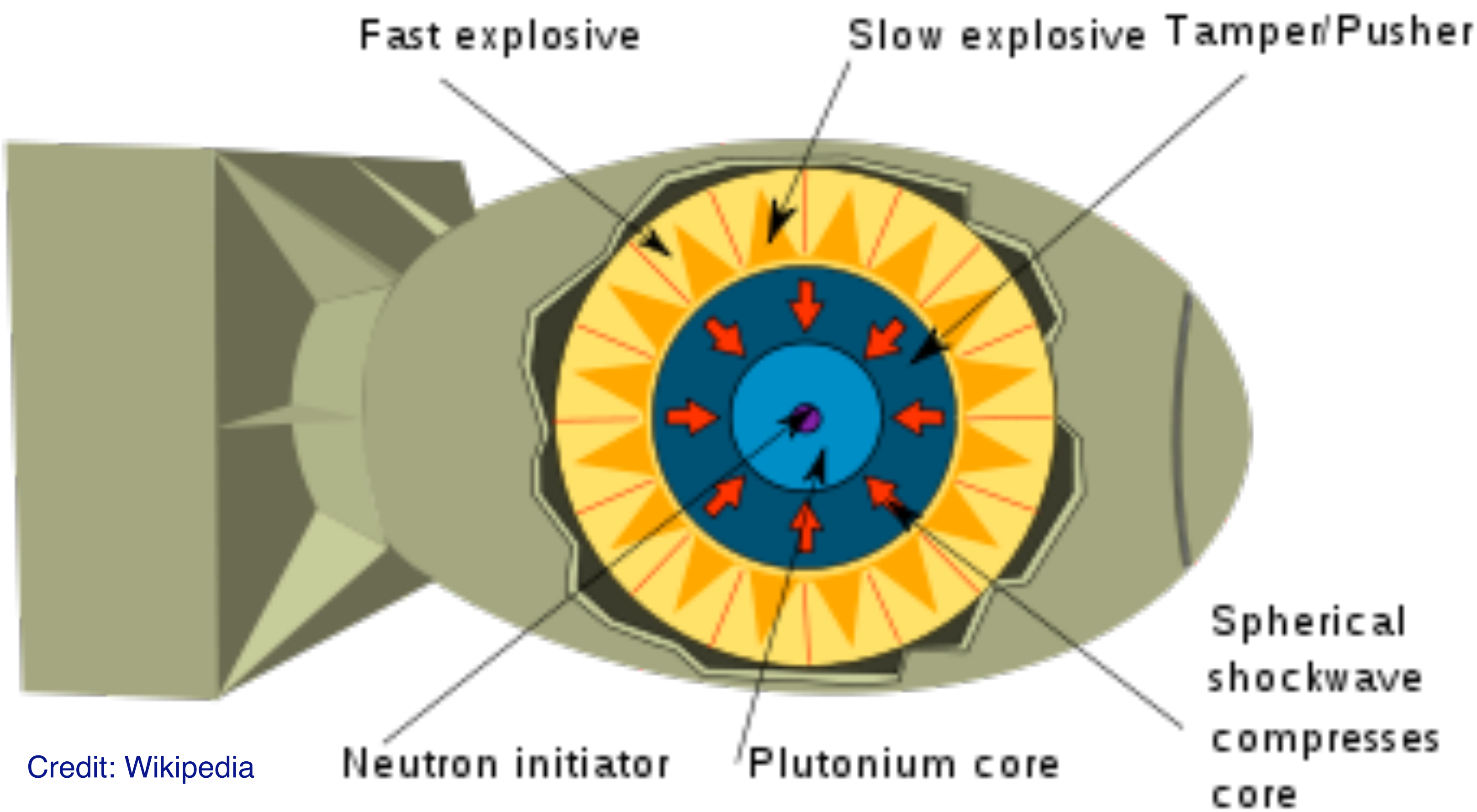
Gun-type fission weapon



Credit: Wikipedia

Works only with highly enriched uranium (HEU)
[relevant today mostly for terrorists or non-state groups]

Implosion-type fission weapon

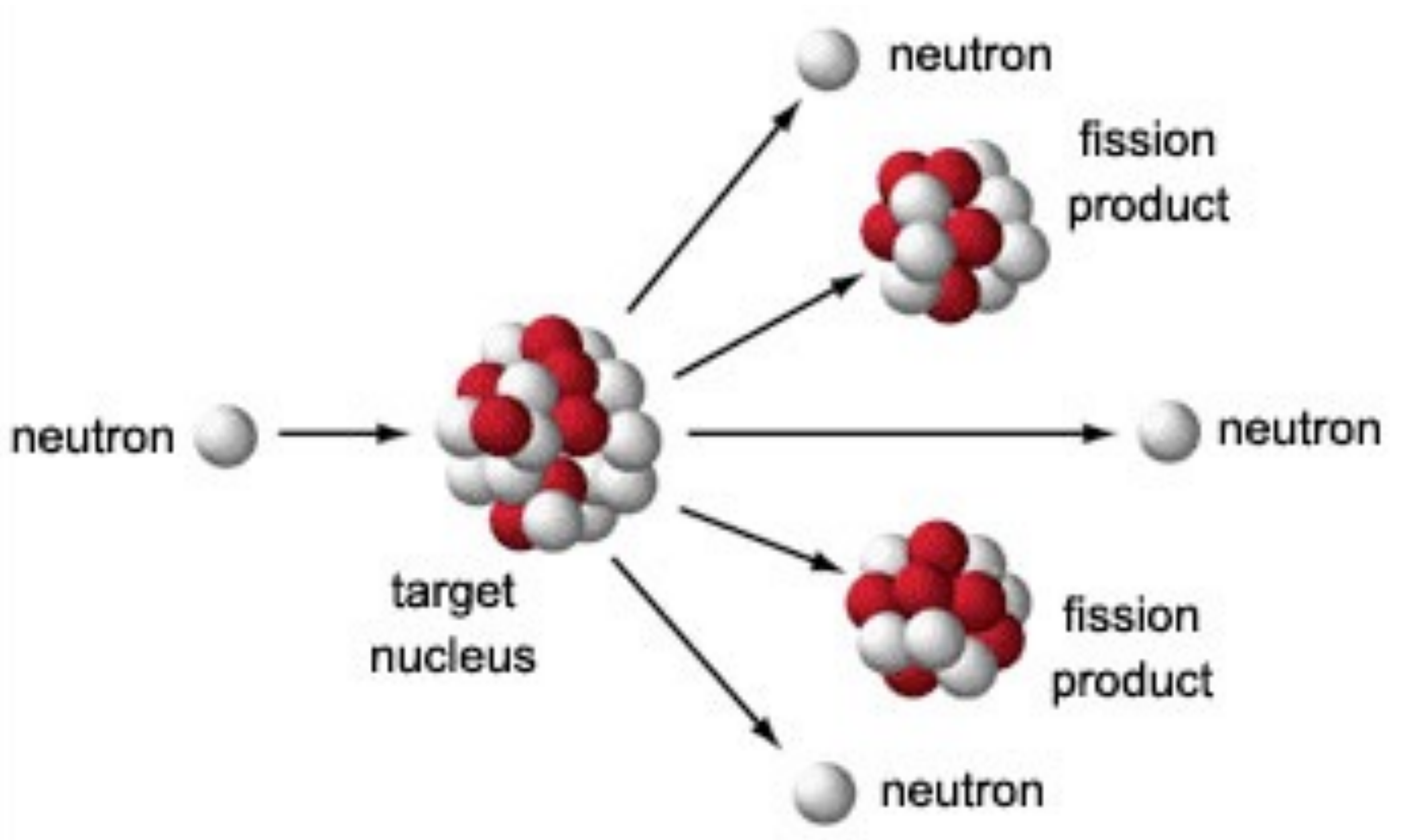


Credit: Wikipedia

Can be used with weapons grade U or Pu

[requires some technical sophistication]

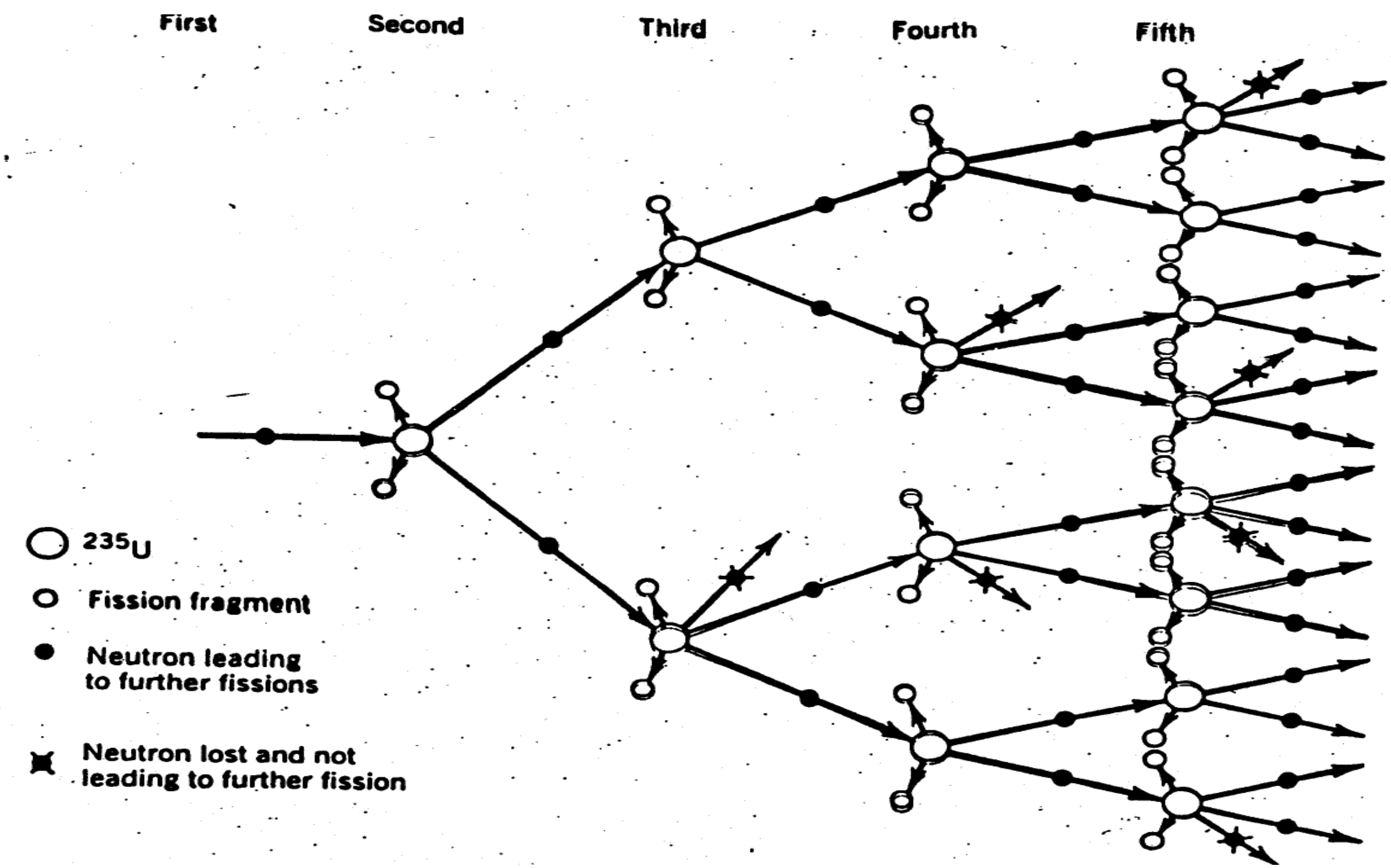
Induced fission



Credit: Atomic Archive

Explosive (fast neutron) chain reaction

A nuclear explosion is achieved by the rapid assembly, in a suitable geometry, of nuclear explosive material with sufficient nuclear reactivity to initiate and sustain a chain reaction driven by <u>fast</u> neutrons.

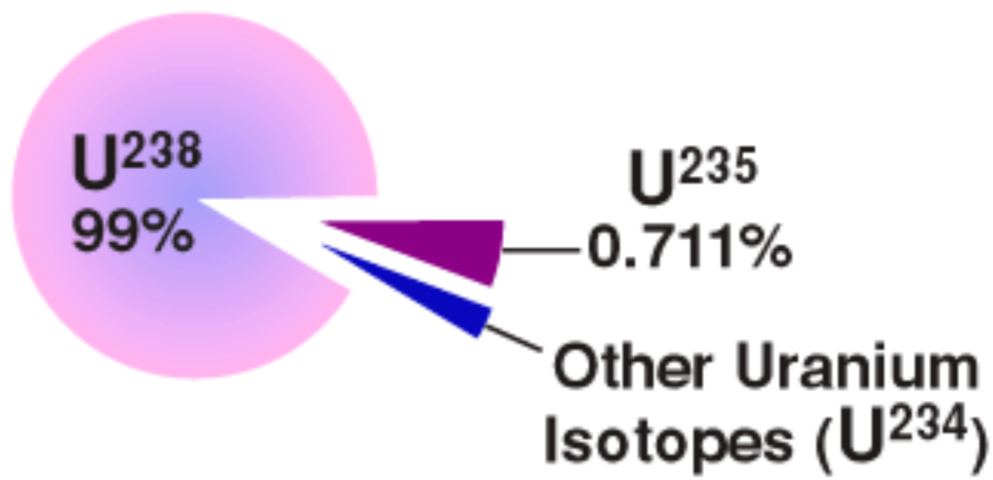


U must be enriched in U-235 to make a bomb

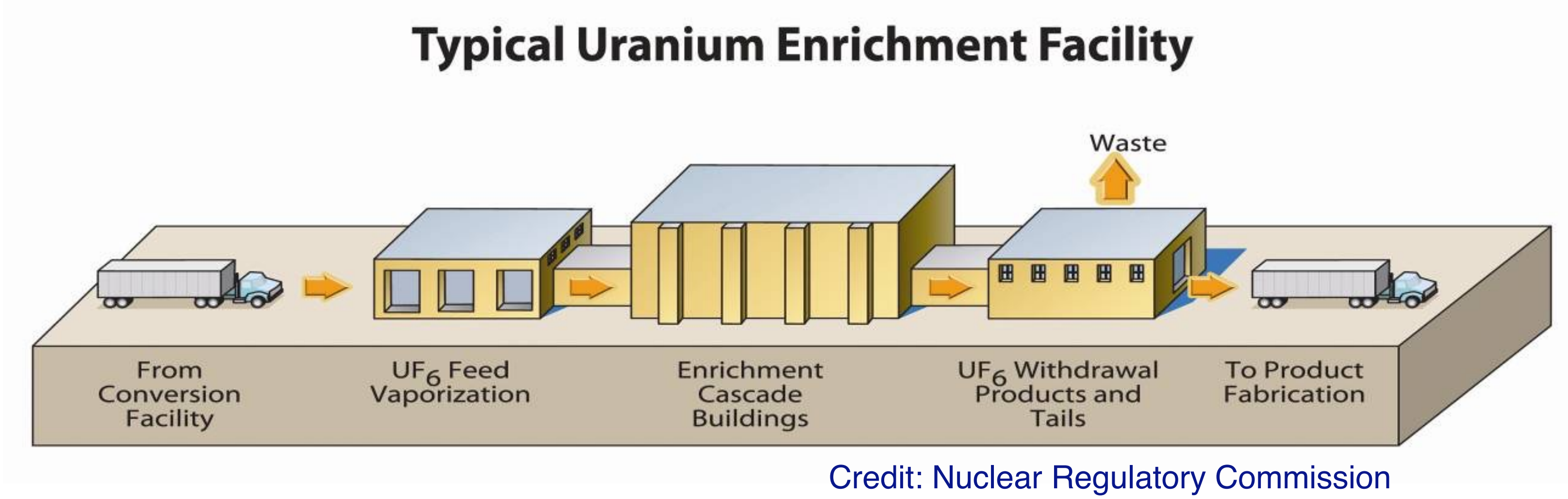
Natural uranium is

– 99.3% U-238 (which is fissionable but not fissile)

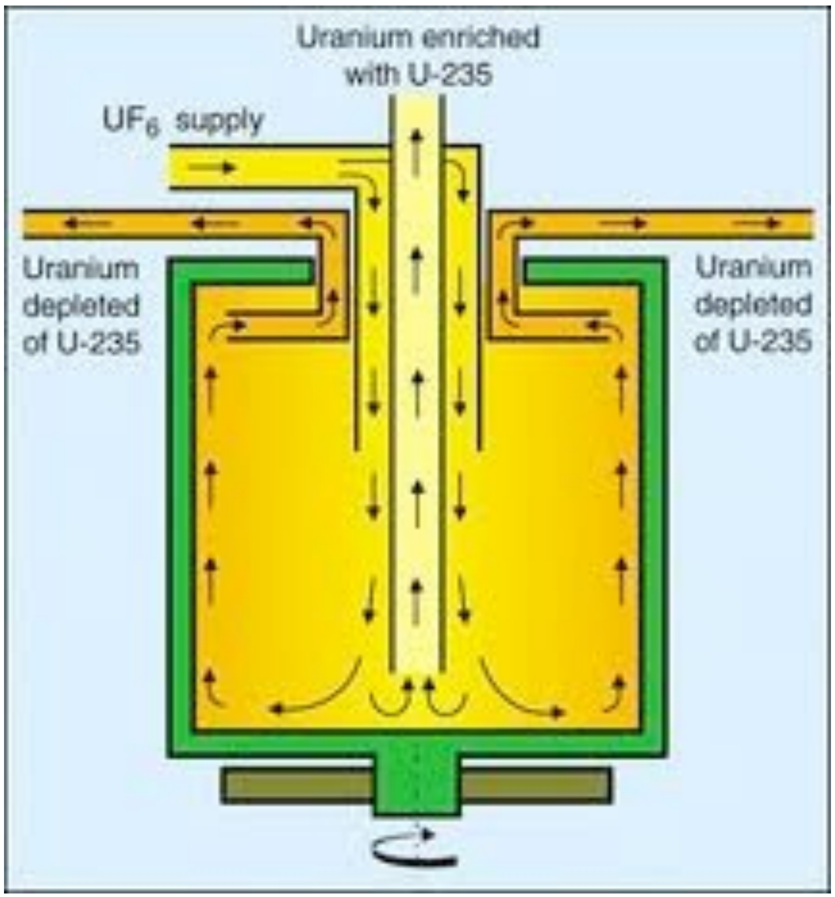
– 0.7% U-235 (which is fissile)



Credit: Nuclear Regulatory Commission



Credit: Nuclear Regulatory Commission



Credit: European Nuclear Society

Centrifuge array at Natanz

Credit: ISNA

Categories of uranium enrichment

LEU = low-enriched uranium (<5% U-235)

MEU = medium-enriched uranium (5–90% U-235)

HEU = highly-enriched uranium (>90% U-235)
(weapons grade)

Plutonium is created in nuclear reactors

The fissile nuclide Pu-239 can be created by bombarding U-238 with neutrons in a nuclear reactor —

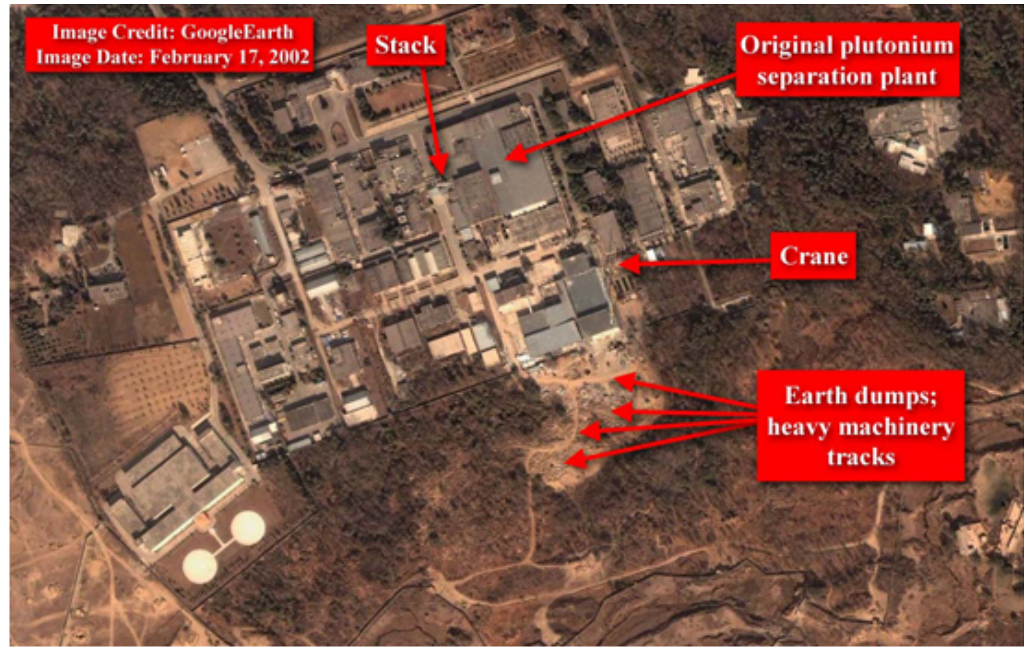
- U-238 + n → Pu-239 (via a two-step process)
  (non-fissile) (fissile)

Credit: Nanking2012

Iran's reactor complex at Arak

Plutonium must then be chemically separated from uranium and other elements

224-B Plutonium Separation Plant, Hanford, WA, 1985
Credit: US DOE



Plutonium Separation Plant Rawalpindi, Pakistan, Feb 2002
Credit: ISIS

Plutonium is extracted from the uranium fuel rods by first dissolving the rods to form a slurry and then extracting the trace amounts of plutonium in the slurry by chemically processing the slurry.

Selected history of Iran's nuclear program

1967 Iran's 1st nuclear reactor, the Tehran Research Reactor (TRR)—which was supplied by the U.S.—goes critical, using U enriched to 93% (converted to run on 20% in 1993)

1970 Iran ratifies the Nuclear Nonproliferation Treaty (NPT)

1974 The Shah, with U.S. support, announces plans to build 23 nuclear power plants and to develop a full nuclear fuel cycle

1979 The Iranian revolution breaks U.S.-Iranian ties; nuclear projects are halted

1984–1996 The U.S. imposes a series of sweeping sanctions on Iran

2002 Iran's nuclear facilities near Natanz and Arak become public knowledge

2003 IAEA calls on Iran to suspend all enrichment and reprocessing related activities and to allow inspectors to conduct environmental sampling at any location; Iran agrees to voluntarily suspend activities and abide by NPT Additional Protocol

2004 IAEA rebukes Iran for not cooperating with IAEA inspectors

2005 Iran begins producing UF_6; IAEA finds Iran noncompliant with NPT safeguards

Selected history of Iran's nuclear program

2006 Iran stops implementing the Additional Protocol and inspection procedures, announces it has enriched U for 1st time, to 3.5%

2006–2009 Sequence of UNSC resolutions and sanctions against Iran; Obama reverses U.S. policy and agrees to talk to Iran; Iranian government agrees to ship most of its LEU abroad and not replace its MEU stock, which has been used up; outcry from all sides in Iran causes the government to withdraw from the agreement

2007 U.S. intelligence community says Iran halted its weapons program in 2003

2010 Iran begins to produce 20% MEU, allegedly for the TRR

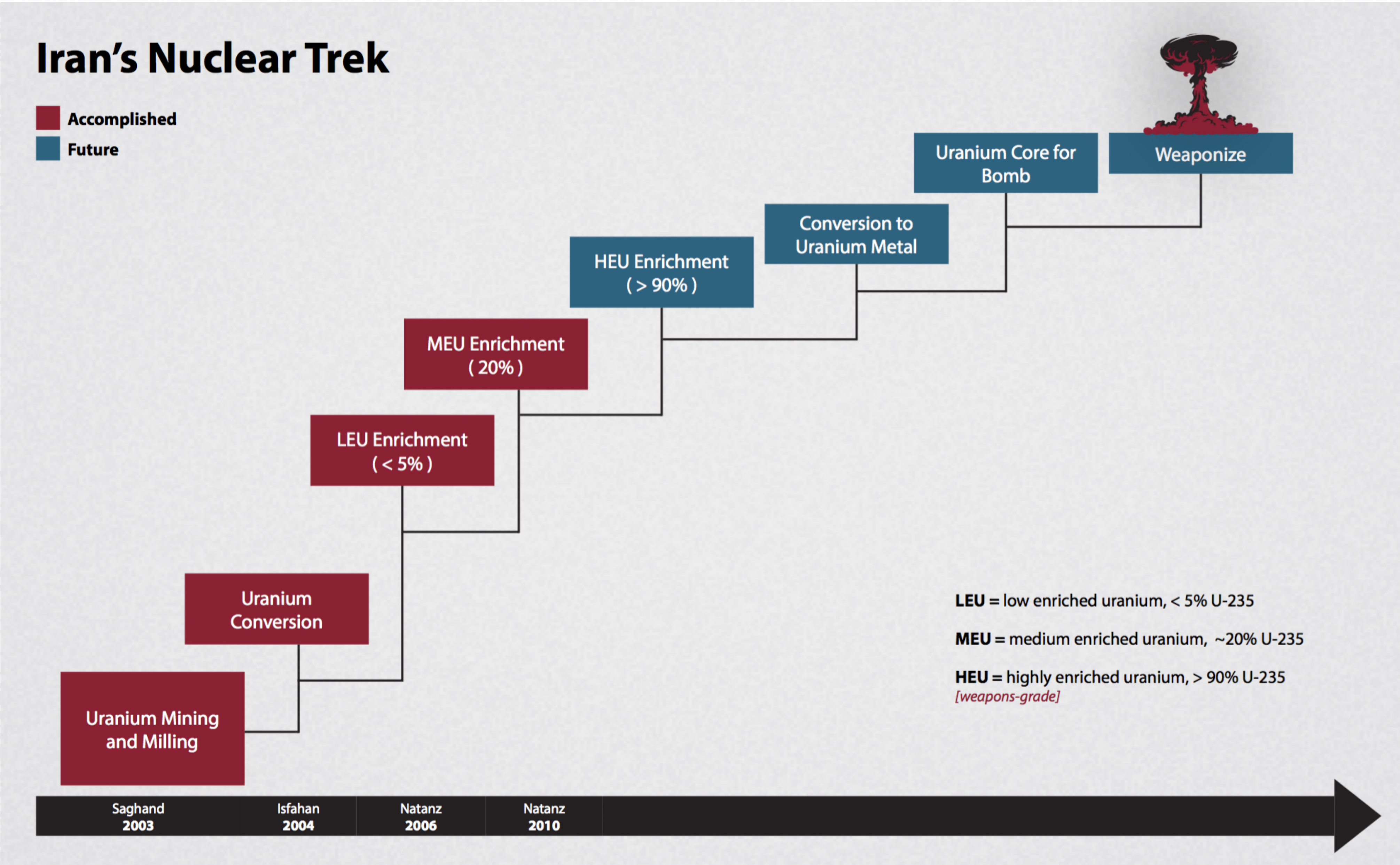
2010–2012 More UNSC resolutions, more sanctions, more negotiations; talks founder over Iran’s insistence on its right to enrich U

2013 Hassan Rouhani elected president of Iran, offers more flexibility, calls for resumption of serious negotiations with the P5+1*; Joint Plan of Action (JPOA) signed, laying out first-phase agreement and a broad framework to guide talks

2014 Implementation of Joint Plan of Action (JPOA) begins, Iran complies fully

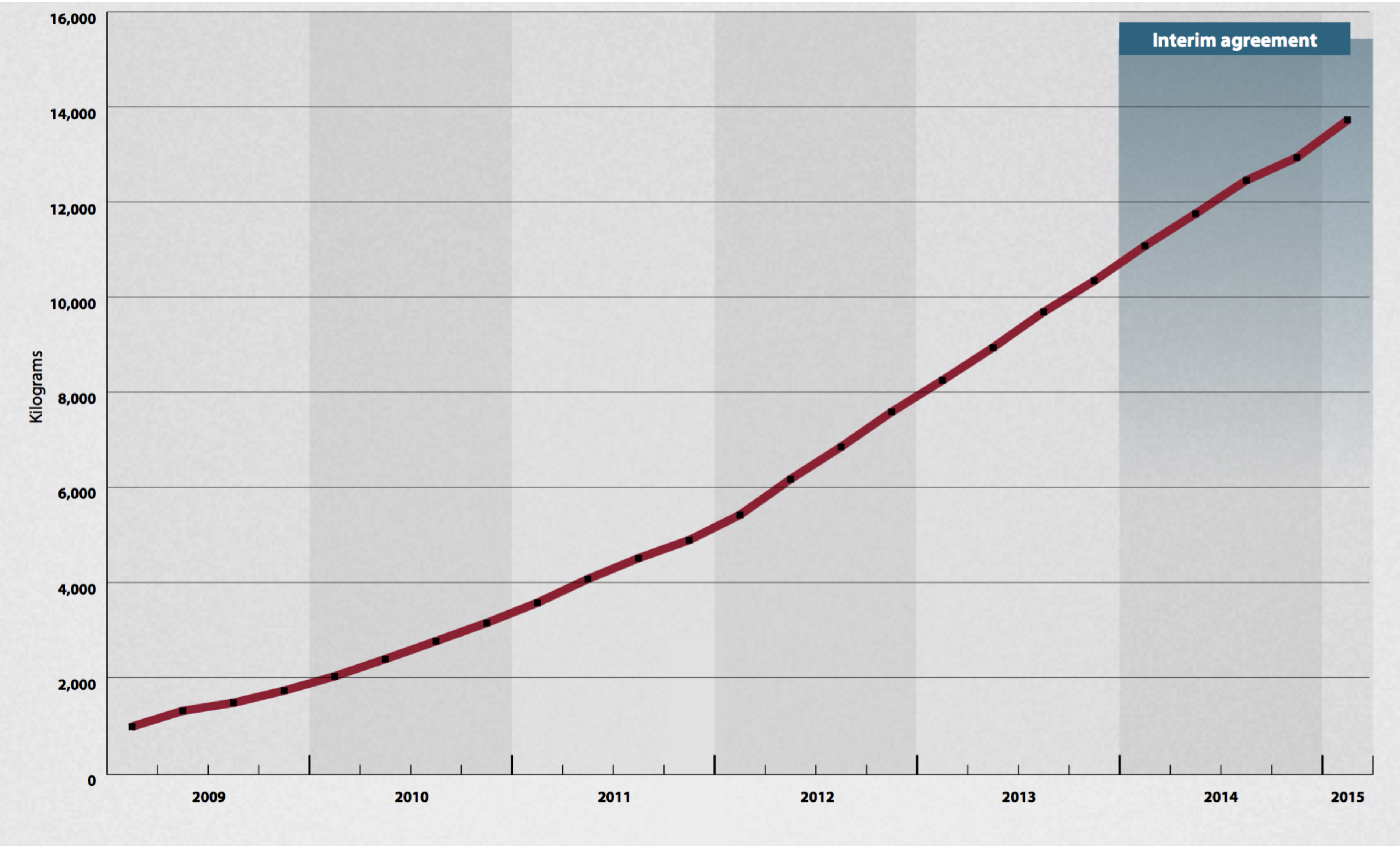
*P5+1 = China, France, Russia, UK, US + Germany

Key steps in Iran’s nuclear program



Credit: Belter Center for Science and International Affairs

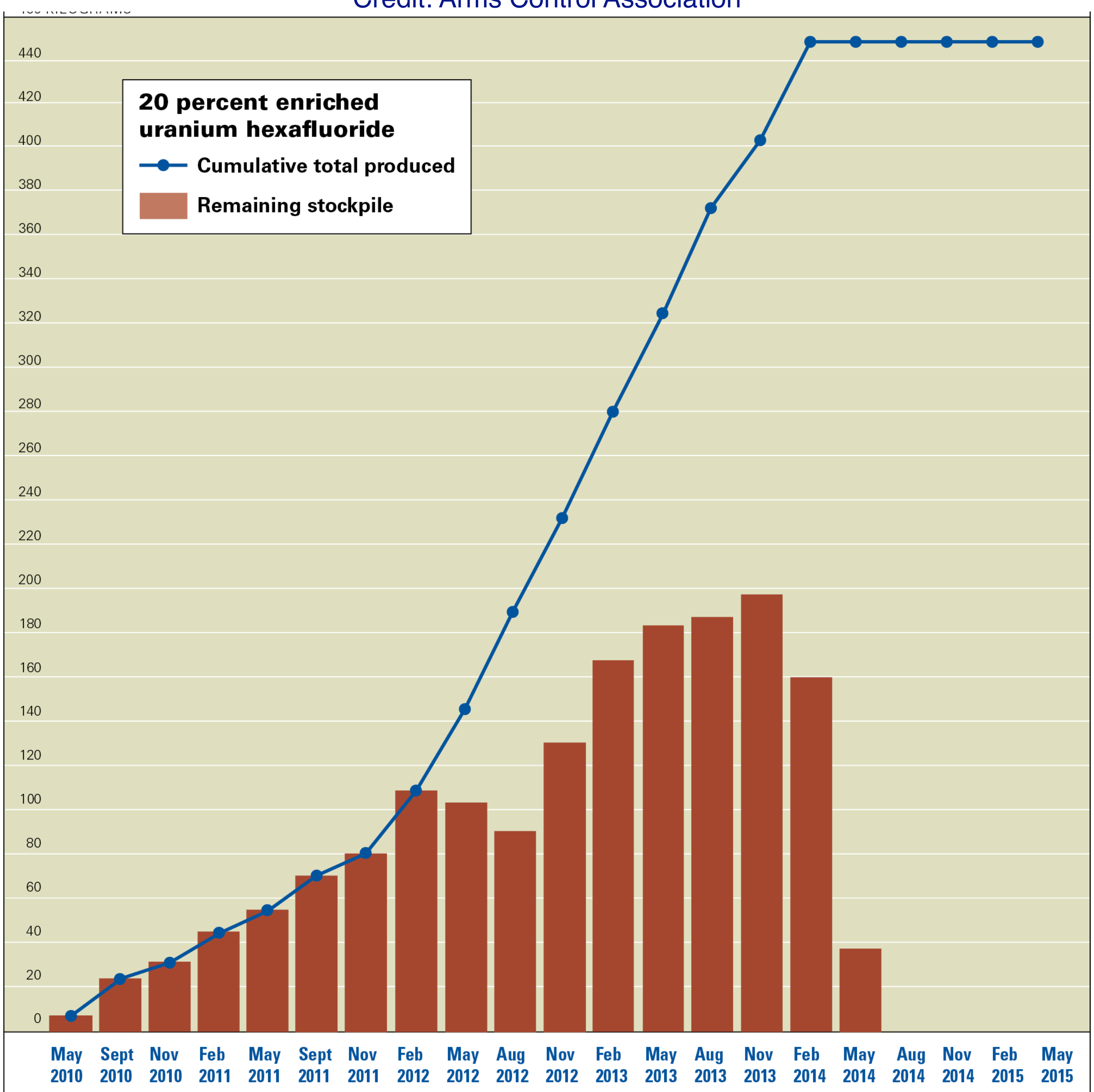
Cumulative LEU production at Natanz



Credit: Belter Center for Science and International Affairs

Iran's 20% enriched uranium eliminated

Credit: Arms Control Association



Context and purposes of the Iran nuclear deal

Prior to the Iran deal —

- Iran was a threshold nuclear weapon state
- In 1–2 months it could have produced enough HEU to make a nuclear weapon
- In 12 months it could have developed and tested a nuclear weapon

Credit: U.S. Department of State

Ernie Moniz

Purposes of the Iran deal —

- Prevent Iran from racing to a bomb for 15–20 years
- Prevent Iran from covertly developing a bomb for 15–20 years
- Key aspect: increase to 12 months the time required for Iran to make enough HEU for a bomb

Components of the Iran nuclear deal

- Joint Comprehensive Plan of Action (JCPOA)
- Nonproliferation Treaty (NPT)*
- NPT Expanded Declaration*
- NPT Additional Protocol*
- Modified Code 3.1 Agreement*

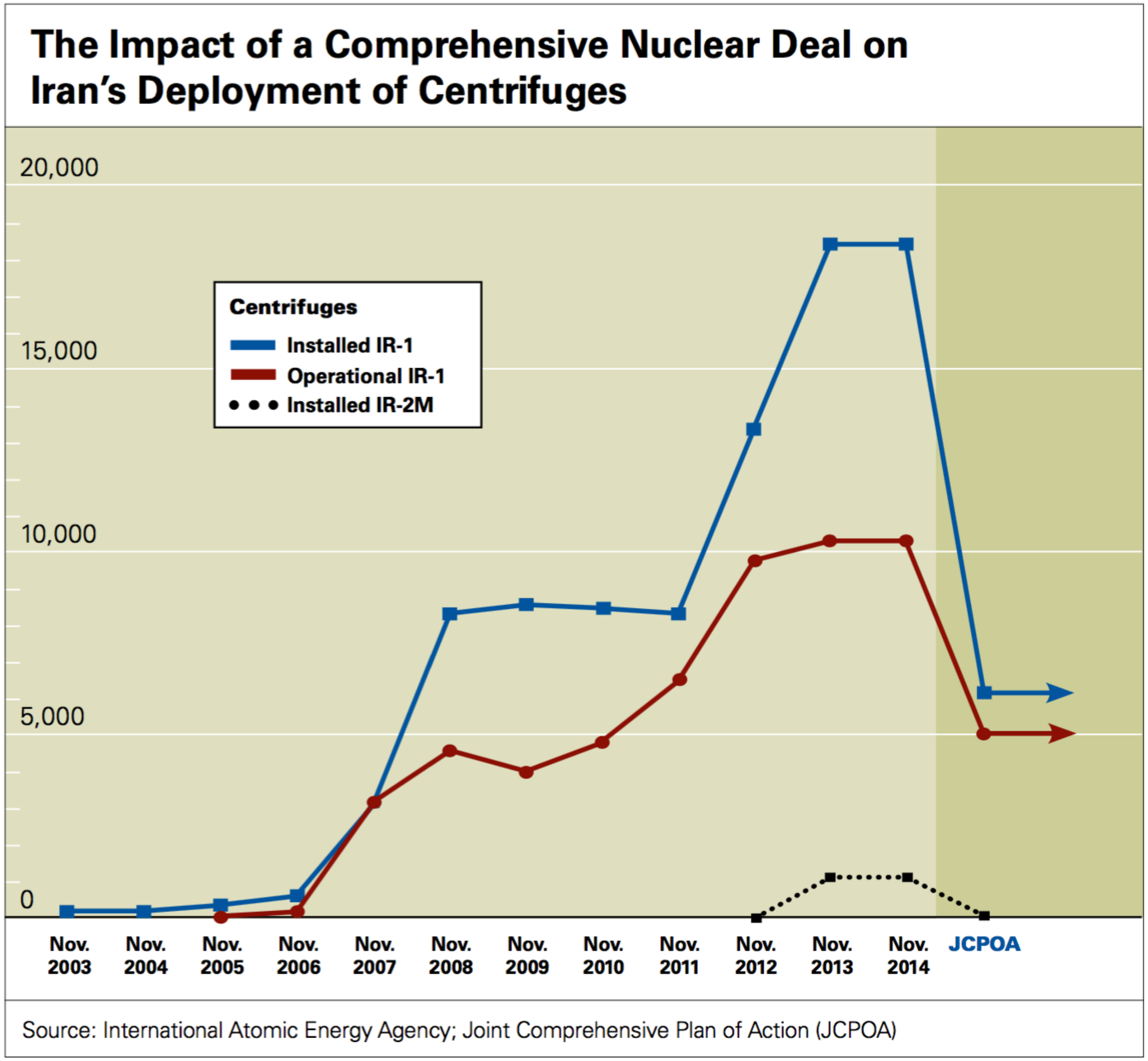
*Iran must comply with these in perpetuity

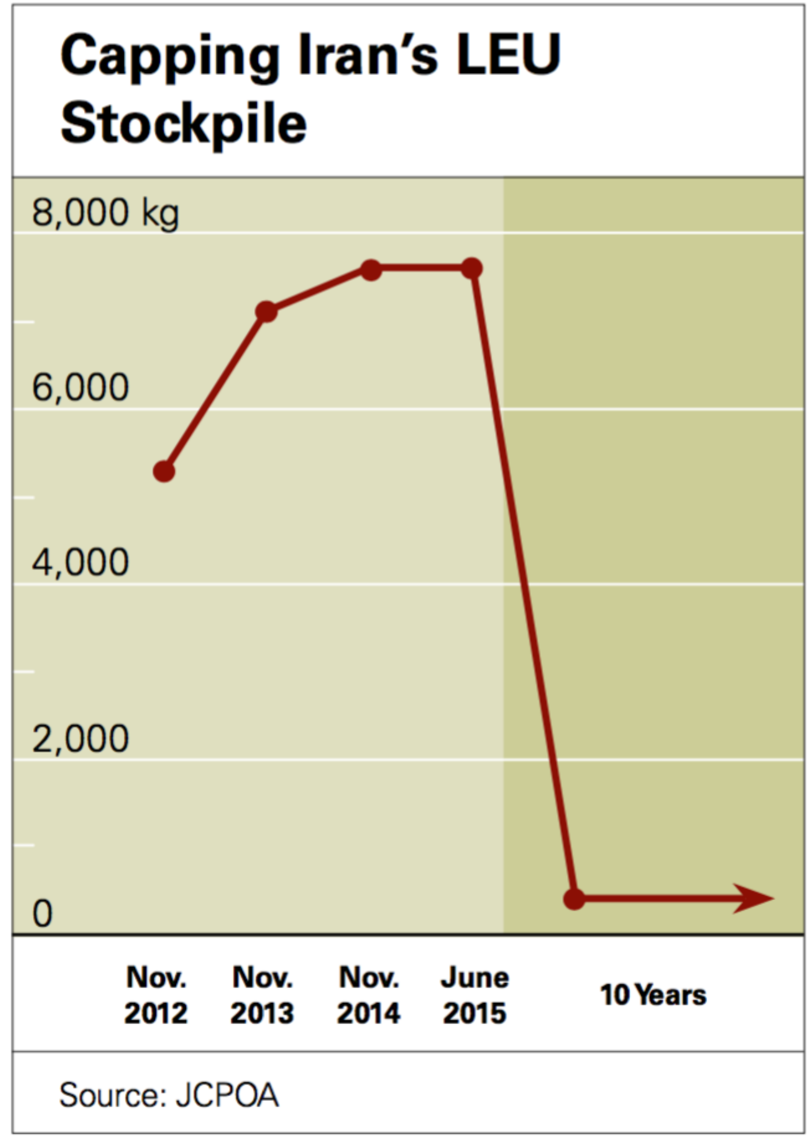
Key Iran deal restrictions and durations

Credit: Belter Center for Science and International Affairs

Uranium route	Plutonium route	Duration
• No enrichment above 3.67% (low-enriched uranium) • Stockpile of low-enriched uranium reduced to 300 kg • No other enrichment facilities • Fordow: 1,044 centrifuges installed (not enriching)	• No construction of additional heavy water reactors • Ship out unused heavy water	15 years
• Natanz: 5,060 centrifuges enriching • Roughly one year breakout • No enrichment using advanced centrifuges (some R&D permitted)		10 years
	• No reprocessing of spent fuel • All spent fuel from Arak shipped out of country for lifetime of reactor	Permanent
	• Destruction or removal of Arak core	

Iran deal cut Iran's centrifuges and LEU stockpile





Credit: Arms Control Association

Iran deal monitoring and verification provisions

Credit: Belter Center for Science and International Affairs

IAEA granted:	Iran agrees:
"Regular access" to all nuclear facilities	To implement Additional Protocol and Modified Code 3.1
Monitoring of nuclear-related purchases from abroad through "dedicated procurement channel"	To "implement an agreed set of measures to address" possible military dimensions
Access to uranium mines and continuous surveillance of uranium mills for 25 years	
"Continuous surveillance" of centrifuge production and storage facilities for 20 years	
Access "to investigate suspicious sites or allegations of covert" nuclear facilities	

Examples of Iran deal verification provisions

Among other things, Iran is required, in perpetuity, to report —

- all nuclear fuel cycle development plans for 10 years ahead
- all nuclear fuel cycle-related R&D activities not involving nuclear material
- all production of uranium and thorium at mines and mills
- all nuclear-related imports and exports
- any production of heavy water or graphite
- manufacture of centrifuge and other enrichment components
- manufacture of flasks for irradiated fuel
- construction of large hot cells
- the location, and any further processing, of nuclear wastes

Examples of Iran deal verification provisions

Iran must, in perpetuity, submit design information for new nuclear facilities as soon as the decision is made to construct them or to authorize construction (Modified Code 3.1)

IAEA inspectors have access rights to —

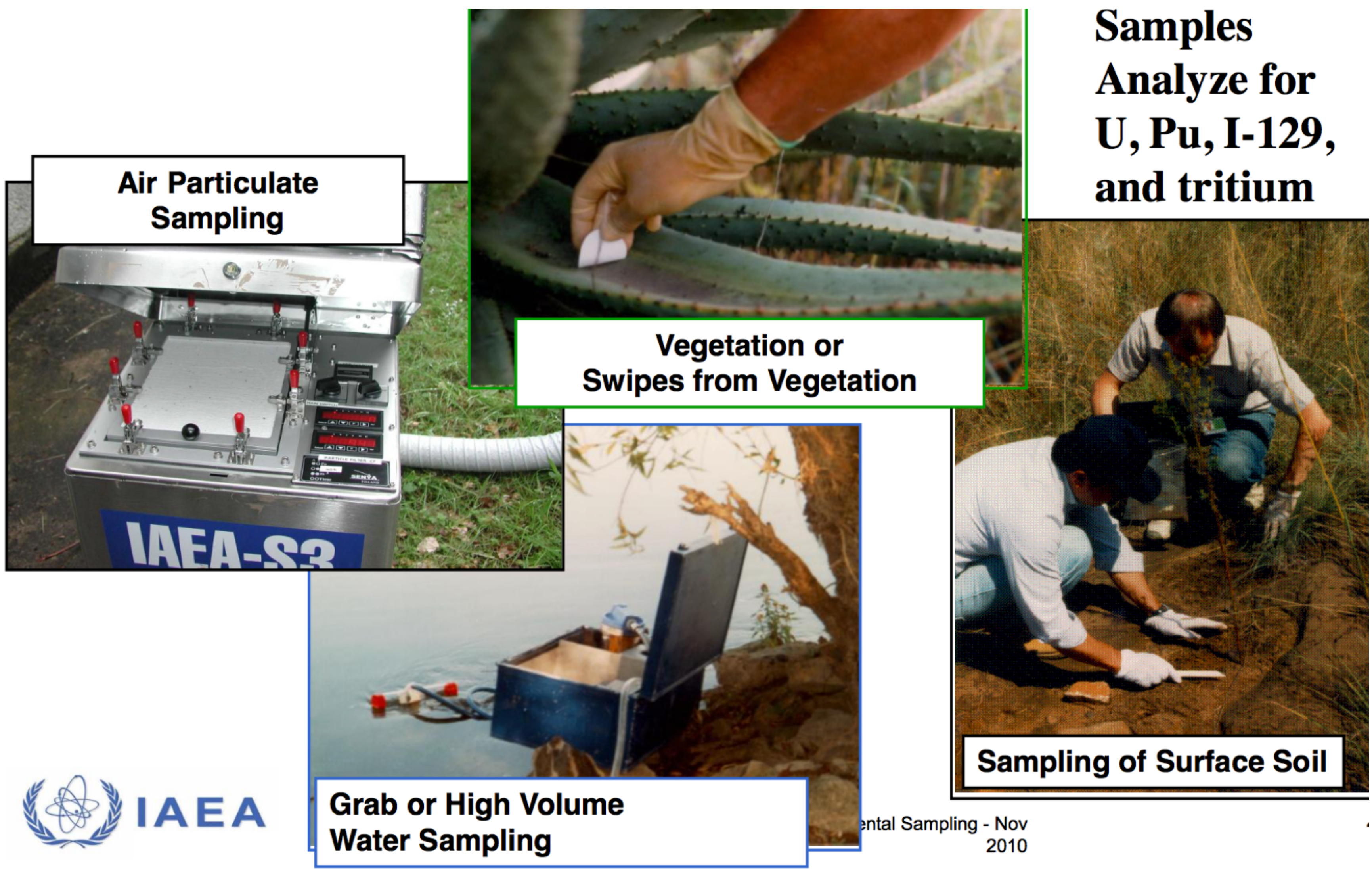
- anywhere on a declared nuclear site
- locations included in the Expanded Declaration
- locations anywhere else that the IAEA identifies for investigation

Timelines for access —

- within 2 hours or less, if carried out with an inspection
- within 24 hours elsewhere
- if Iran contests an inspection at an undeclared or military facility, that triggers a process that guarantees access within 24 days

Swipe sampling of equipment

Other examples of environmental sampling



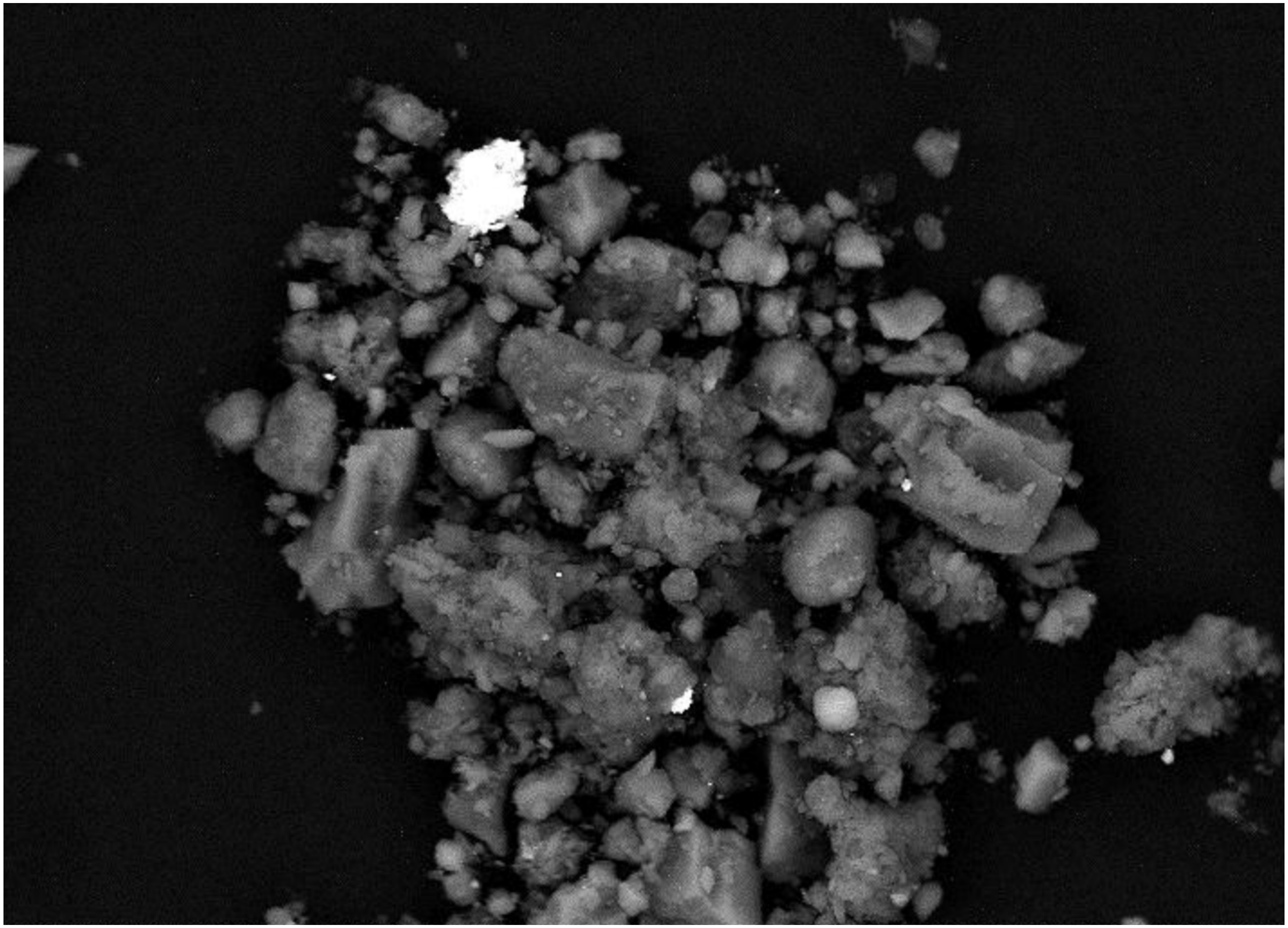
Current environmental sampling capabilities

Environmental sampling for verifying compliance is based on strong evidence that every nuclear process—no matter how leak tight—emits small amounts of material to the environment.

Current verification techniques can locate micron-sized particles of nuclear materials and determine their composition.

Current analytical techniques can detect *picograms of U* (10^{-12} g = parts per trillion) and *femtograms of Pu* (10^{-15} g = parts per quadrillion) and determine their isotopic composition and the implications for compliance with the Iran deal.

Environmental sampling capabilities



Credit: D. Donohue, IAEA-CN-184/159

SEM image of 1 micron U particles in a silica matrix

Implementation of the Iran deal

2015 July 14 Iran and P5+1 announce a comprehensive deal

July 20 UN Security Council unanimously endorses the deal

Aug 15 IAEA confirms that Iran is addressing its unresolved concerns

Sept 9 IAEA submits follow-up questions to Iran

Sept 17 Motions in U.S. Senate to vote on disapproval end

Sept 20 IAEA carries out environmental sampling at the Parchin site

Oct 14 Iran's Parliament and Guardian Council ratify the Iran Deal

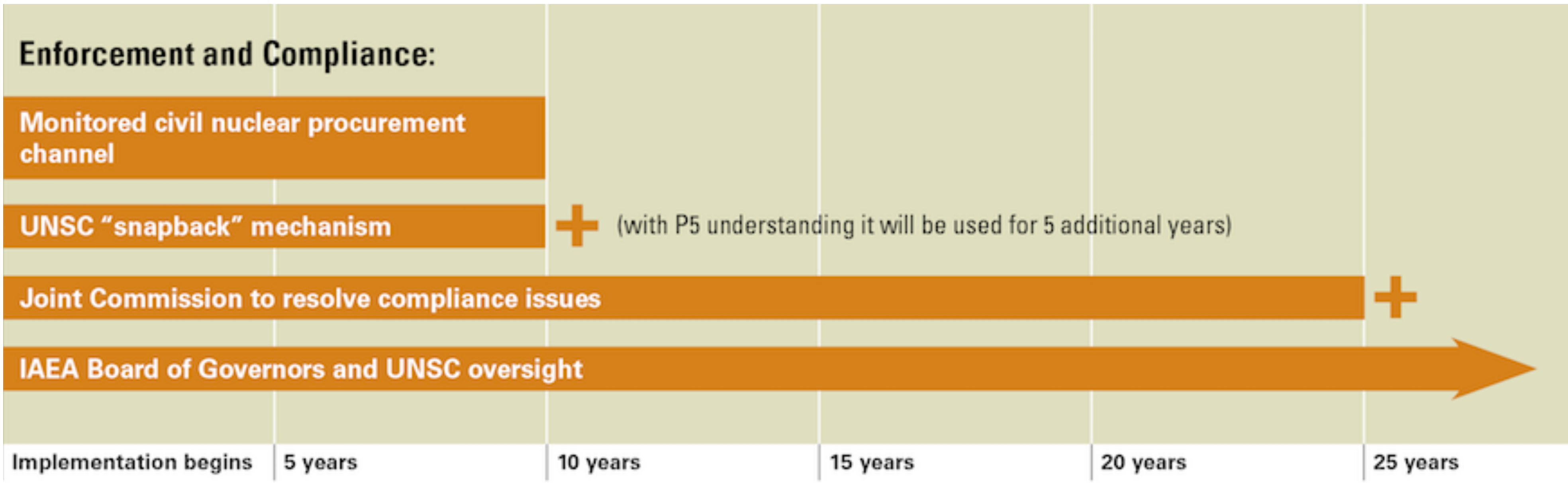
Dec 2 IAEA reports on possible military dimensions of Iran's nuclear program

Iran disassembles centrifuges, ships MEU and LEU to Russia, pours concrete into the core of the Arak nuclear reactor.

2016 Jan 16 – Implementation Day IAEA verifies that Iran has met its commitments, triggering the lifting of nuclear-related sanctions

Incentives for Iran's continued compliance

Credit: Arms Control Association



Conclusions

In my judgment, the Iran nuclear deal is a major arms control accomplishment.

It has set back the time required for Iran to produce enough HEU for a nuclear bomb to ~1 year.

It has made it possible for the IAEA to detect any open or clandestine effort by Iran to develop a bomb.

I think this deal makes it very unlikely that Iran will move toward developing a nuclear weapon in the next 15 years.

I think it is the most effective, realistic way to minimize the chance that Iran will ever develop a nuclear weapon.