The Iran nuclear deal
Scientific and policy aspects

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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
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?

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

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Credit: AEC
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

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

Credit: Wikipedia
Implosion-type fission weapon

Can be used with weapons grade U or Pu
[requires some technical sophistication]
Induced fission

Credit: Atomic Archive
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 fast 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
Typical Uranium Enrichment Facility

Credit: Nuclear Regulatory Commission

Centrifuge array at Natanz

Credit: ISNA

The Iran Nuclear Deal

UIUC Physics Colloquium February 3, 2016

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

\[ \text{U-238} + n \rightarrow \text{Pu-239} \text{ (via a two-step process)} \]

(non-fissile) \hspace{1cm} (fissile)

Plutonium is created in nuclear reactors

Iran’s reactor complex at Arak
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 UF₆; 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

- **Uranium Mining and Milling**
  - Saghand: 2003
  - Isfahan: 2004
  - Natanz: 2006
  - Natanz: 2010

- **LEU Enrichment (<5%)**
- **MEU Enrichment (20%)**
- **HEU Enrichment (>90%)**
- **Conversion to Uranium Metal**
- **Uranium Core for Bomb**
- **Weaponize**

**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
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

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

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

Credit: Belter Center for Science and International Affairs
Iran deal cut Iran’s centrifuges and LEU stockpile

The Impact of a Comprehensive Nuclear Deal on Iran’s Deployment of Centrifuges

Capping Iran’s LEU Stockpile

Source: International Atomic Energy Agency; Joint Comprehensive Plan of Action (JCPOA)

Source: JCPOA

Credit: Arms Control Association
# Iran deal monitoring and verification provisions

**Credit:** Belter Center for Science and International Affairs

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

Samples
Analyze for U, Pu, I-129, and tritium

Air Particulate Sampling

Vegetation or Swipes from Vegetation

Grab or High Volume Water Sampling

Sampling of Surface Soil
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* \((10^{-12} \text{ g} = \text{parts per trillion})\) and *femtograms of Pu* \((10^{-15} \text{ g} = \text{parts per quadrillion})\) and determine their isotopic composition and the implications for compliance with the Iran deal.
Environmental sampling capabilities

SEM image of 1 micron U particles in a silica matrix

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

<table>
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<th>Enforcement and Compliance:</th>
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<tbody>
<tr>
<td>Monitored civil nuclear procurement channel</td>
<td>+</td>
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<tr>
<td>UNSC “snapback” mechanism</td>
<td>+</td>
</tr>
<tr>
<td>Joint Commission to resolve compliance issues</td>
<td>+</td>
</tr>
<tr>
<td>IAEA Board of Governors and UNSC oversight</td>
<td>+</td>
</tr>
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- Implementation begins: 5 years
- 10 years
- 15 years
- 20 years
- 25 years

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.