The Iranian Nuclear Program

Timelines, Data, and Estimates

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Current as of 25 JAN 2012 using data from IAEA report dated 18 NOV 2011

Scope, Content, and Estimates

This product is an exposition of the technical data contained in numerous International Atomic Energy Association (IAEA) reports informed by the discussions of experts in the field of nuclear proliferation. It is a work-in-progress in that it will be revised continuously based on new information from the IAEA and other sources and on feedback from readers.

We welcome your informed commentary on the technical considerations presented in this document. Please send your comments, with references to source-data or documentation, to INP@AEI.ORG.

This product does NOT contain policy recommendations. It is intended solely to inform the policy community and the American public about the nature and progress of the Iranian nuclear program.

This product does NOT assess Iran's intentions to weaponize or to pursue break-out scenarios. It is focused entirely on technical feasibility.

This document contains the following sections:

1) Overall assessment of the Iranian nuclear program, with timelines for breakout capabilities under various scenarios.
2) Description of the assumptions underlying those estimates and scenarios.
3) Detailed consideration of Iran's production of 19.75% low-enriched uranium (LEU) under several scenarios
4) Assessment of the effects of sanctions and the direct actions against Iranian nuclear scientists and engineers on the program
5) Depictions of the path to weaponization and a graphical status of the Iranian weaponization program
6) Graphical depiction and explanation of the process of enrichment
7) Locations, construction, centrifuge installations, and uranium stockpiles at the Natanz and Fordow enrichment facilities
8) Sources

Estimates for FEB 2012 IAEA Report *(assuming data measured on 8 FEB 2012)*

3.5% LEU	FEB 2012 (est.)	NOV 2011 (actual)	Change	Confidence
Centrifuges enriching at Natanz:	6,720	6,208	+512	low
LEU produced at Natanz (elemental uranium):	3,701 kg	3,298 kg	+403 kg	moderate
19.75% LEU				
Centrifuges enriching at Natanz PFEP:	328	328	0	high
Centrifuges enriching at Fordow:	348	0	+348	high
LEU produced at PFEP and Fordow:	64.0 kg	53.4 kg	+10.6 kg	moderate to high
HEU (60% or 90%) at declared facilities	none	none	0	high
Centrifuges enriching				
IR-1	7,396	6,536	+860	low
IR-2	0	0	0	high
IR-4	0	0	0	high

Iran Nuclear Timeline

Worst-Case and Most Likely Case Breakout Scenarios

Assessment

Iran COULD acquire enough weapons-grade uranium for one weapon within **ONE MONTH** of starting to race.
This scenario is **HIGHLY UNLIKELY**.

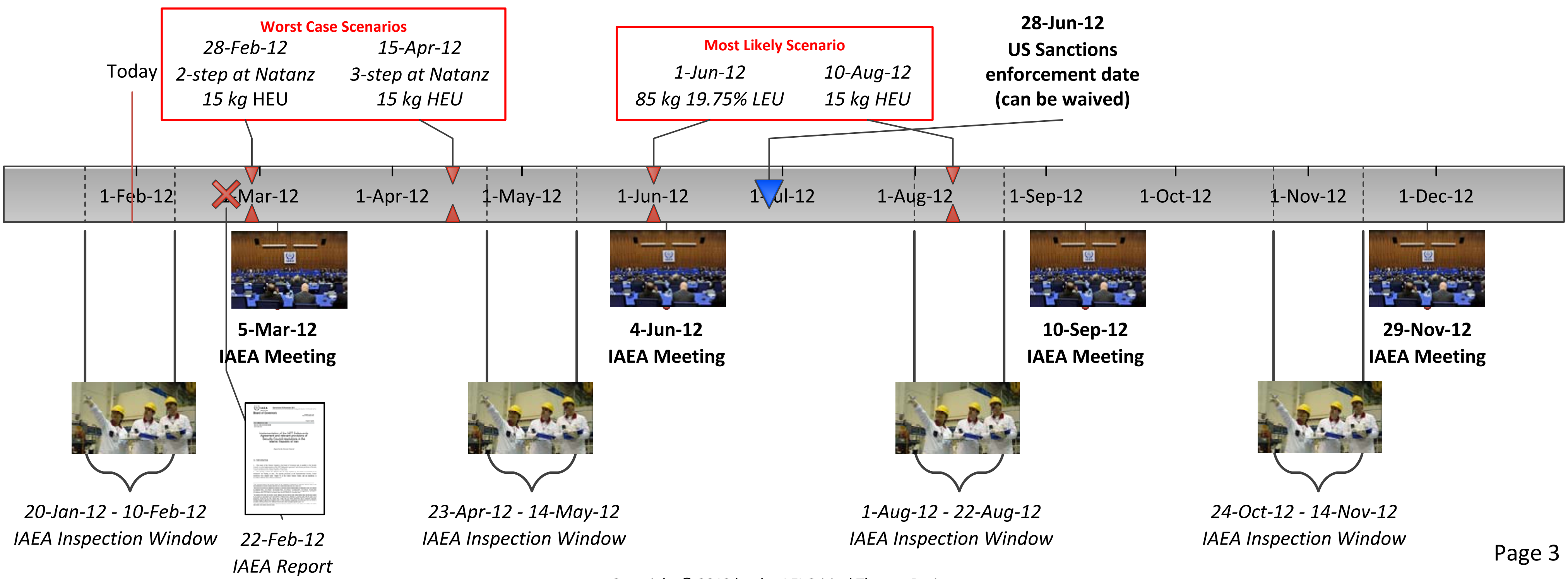
Iran CAN acquire weapons-grade uranium for one weapon by **MID-AUG 2012** under currently-announced plans for expanding enrichment.
This scenario is **SOMEWHAT LIKELY**.

Iran WILL acquire enough 19.75% uranium by **1 JUN 2012** to be within **2.5 MONTHS** of producing weapons-grade uranium for one 15 kiloton bomb **under certain contested technical assumptions**. This scenario is **MOST LIKELY**.

See next page for the facts and assumptions underlying these estimates.

Current as of 25 JAN 2012 using data from IAEA report dated 18 NOV 2011

Bold dates are fixed; *italicized* dates are estimates
Listed inspection windows are approximate. IAEA may conduct inspections outside of these windows



Atomic Weapons Data

- Small atomic weapons can be built from cores consisting of 10-25 kg of uranium enriched to 90% U-235 (weapon-grade high-enriched uranium, or HEU).
- The explosive yield of a 15 kg core is on the close order of 15 kilotons.
- Uranium can be enriched to HEU in a two-step or a three-step process.
- Both processes begin by enriching natural uranium (0.7% U-235) to 3.5% (low-enriched uranium, or LEU).
- The two-step process enriches from 3.5% LEU to 19.75% LEU, and then from 19.75% LEU directly to 90% HEU.
- The three-step process proceeds from 3.5% LEU to 19.75% LEU, from 19.75% LEU to 60% HEU, and then from 60% HEU to 90% HEU.
- The most important difference between these processes is the amount of LEU required initially—the time required to enrich from 19.75% to 90% is virtually the same for either process.
- The two-step process requires 85 kg of 19.75% LEU using interconnected cascades (such as are at Fordow) or 116 kg using non-interconnected cascades (such as those at Natanz). The three-step process requires significantly more—243 kg in non-interconnected cascades (such as at Natanz; we are still calculating the amount that would be required at Fordow).
- There is disagreement among experts about Iran's ability to execute a two-step process with its current technology and cascade configuration.
- If Iran were forced to use a three-step process, the primary delay would result from the time required to produce the additional 19.75% LEU, a factor that Iran could affect either by bringing more centrifuge cascades online or by beginning to enrich with more efficient centrifuges, some of which are already installed but not yet enriching.

Breakout Scenarios

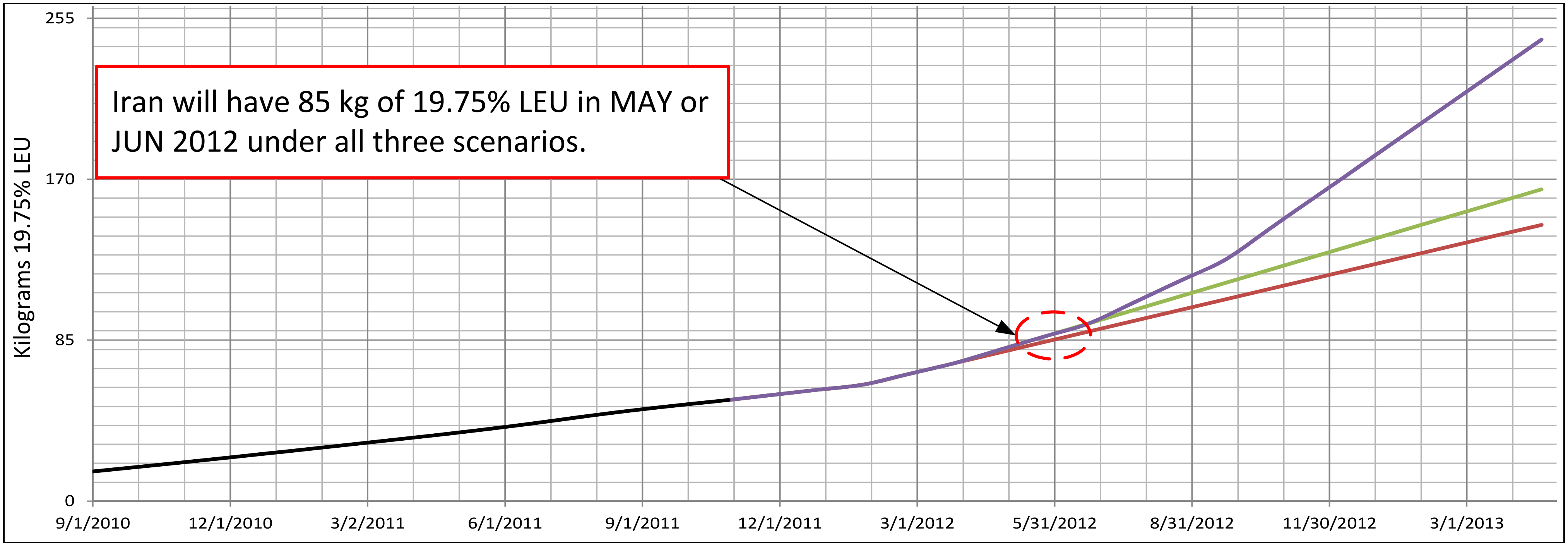
Worst-case

- The worst-case scenarios assume that Iran devotes all operational centrifuges at Natanz to producing first 19.75% LEU and then 90% HEU, ceasing production of 3.5% LEU. Such actions would be visible to inspectors and so would most likely occur between inspections. Iranian nuclear policy and strategy does not appear to be going down this road.
- The scenarios assume 6,208 centrifuges spinning (the number being fed uranium as of 18 NOV 2011) operating with an efficiency of 0.9 separative work units (SWU)/centrifuge/year (roughly the efficiency they have demonstrated).
- Both scenarios assume that Iran begins to race to breakout on 1 FEB.
- In the first case, producing 116 kg of 19.75% LEU and then enriching directly to 90% HEU; in the second case, producing 243 kg of 19.75% LEU, then enriching to 60% HEU and then to 90% HEU.
- *These calculations assume tails assays of 2.0% and 9.3% for the two steps in the first process and 2.0%, 12.0%, and 41.1% for the three steps in the second process. These data are derived from the Natanz facility; the Fordow installations are notably more efficient with lower tails assays.*

Most Likely

- The 6,208 centrifuges in the main cascade at Natanz continue to produce 3.5% LEU and are not diverted to higher-level enrichment
- Enrichment to 19.75% occurs in four cascades totaling 676 IR-1 centrifuges (2 interconnected at the Natanz PFEP and 2 interconnected at Fordow).
- At least one additional cascade is brought online at Fordow by the end of MAR 2012, adding 164 IR-1 centrifuges.
- The scenarios also consider the possibility that Iran starts enriching with 1 cascade of IR-2 centrifuges (164 total) in JUN 2012 either at Natanz (where they are currently installed and under vacuum) or after moving them to Fordow. It adds another 2 cascades of IR-2 centrifuges (328 total) at Fordow in AUG 2012 and stops enriching at the 2 IR-1 cascades at the Natanz PFEP.
- Estimates for all three of these sub-scenarios are on the next page.
- *These calculations assume tails assays of 0.7% and 4.6% for the two steps. The difference in the tails between the scenarios reflects the fact that the cascades at PFEP and Fordow are interconnected.*

Iran's Capacity To Produce 19.75% LEU under Announced Plans



Scenarios

1) **RED**. Iran enriches to 19.75% with 2 cascades totaling 328 IR-1 centrifuges at the Natanz PFEP and 2 cascades totaling 348 IR-1 centrifuges at Fordow. **The IAEA confirmed in JAN 2012 that Iran had begun enriching to 19.75% in 2 cascades at Fordow.**

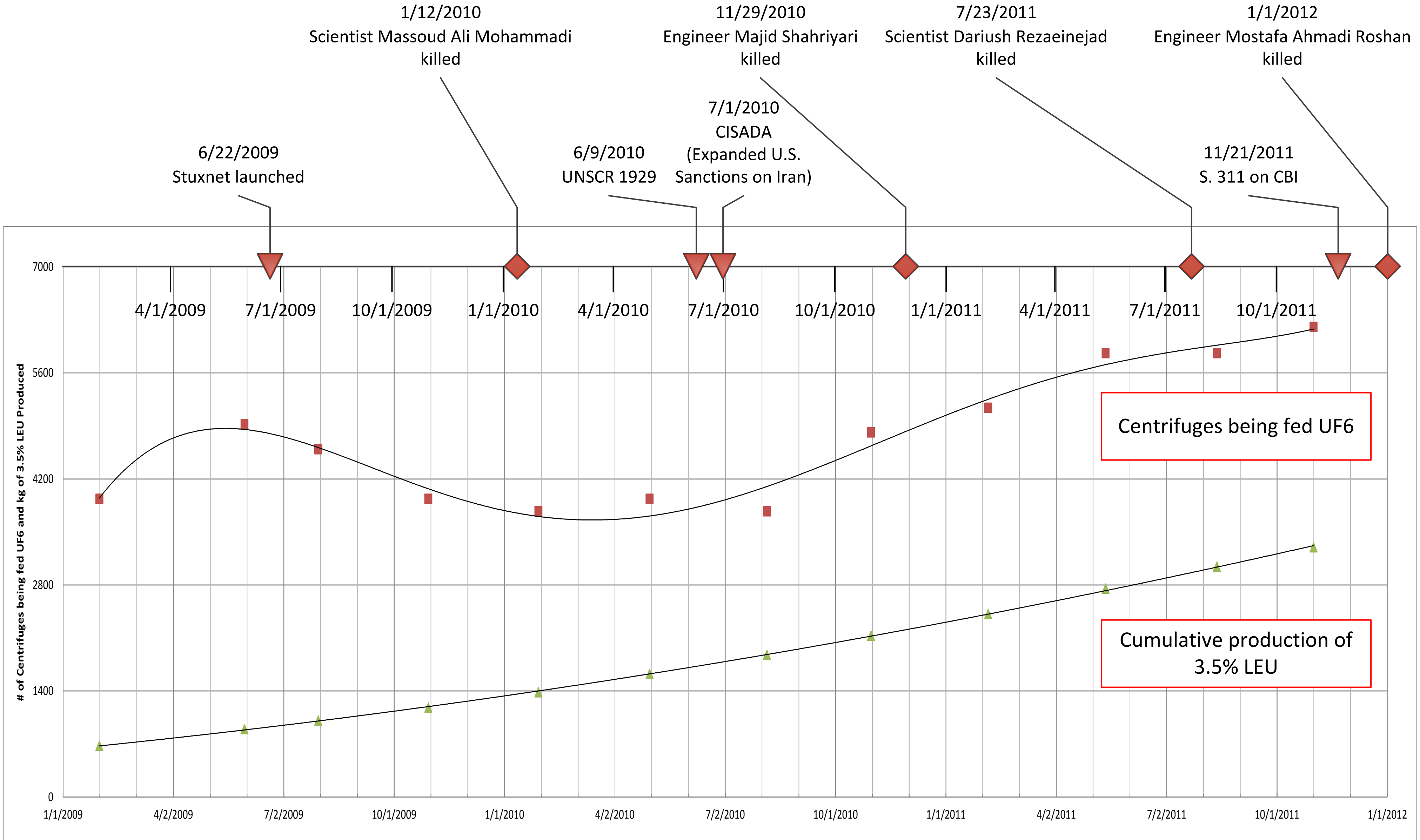
2) **GREEN**. Same as Scenario 1, but in MAR 2012, Iran adds 1 cascade of 174 IR-1 centrifuges to the 2 already operating at Fordow and continues enriching in the 2 cascades (328 IR-1 centrifuges total) at the Natanz PFEP. **The IAEA reported on 18 NOV 2011 that there were an additional 64 IR-1 centrifuges at Fordow. This scenario assumes that Iran completed one additional cascade within six months of that report.**

3) **PURPLE**. Same as Scenario 2, but in JUN 2012 Iran starts enriching with 1 cascade of IR-2 centrifuges (164 total) either at Natanz (where they are currently installed and under vacuum) or after moving them to Fordow. It adds another 2 cascades of IR-2 centrifuges (328 total) at Fordow in AUG 2012 and stops enriching at the 2 IR-1 cascades at the Natanz PFEP. **The IAEA has not reported Iran using IR-2 centrifuges in full cascades to enrich at Natanz and has not reported any present at Fordow.**

Methodology note: Estimates for the addition of new cascades were produced as follows. From IAEA reports of the amount of 19.75% LEU produced in each period and the number of centrifuges reportedly running during that period, we calculated the average daily production of 19.75% LEU per centrifuge per day. The first two data periods (in which the IAEA reported that only one cascade was running) generated production rates roughly twice as high as those of the following periods when both cascades were running. We discarded these two anomalous results and used the average of the five most recent data periods, generating an average production rate of 0.277 grams of 19.75% LEU per centrifuge per day. We then used this estimated production rate to calculate overall production rates for additional centrifuge cascades as they are predicted to come on line.

Effects of Sanctions and Direct Action on Iranian Nuclear Enrichment

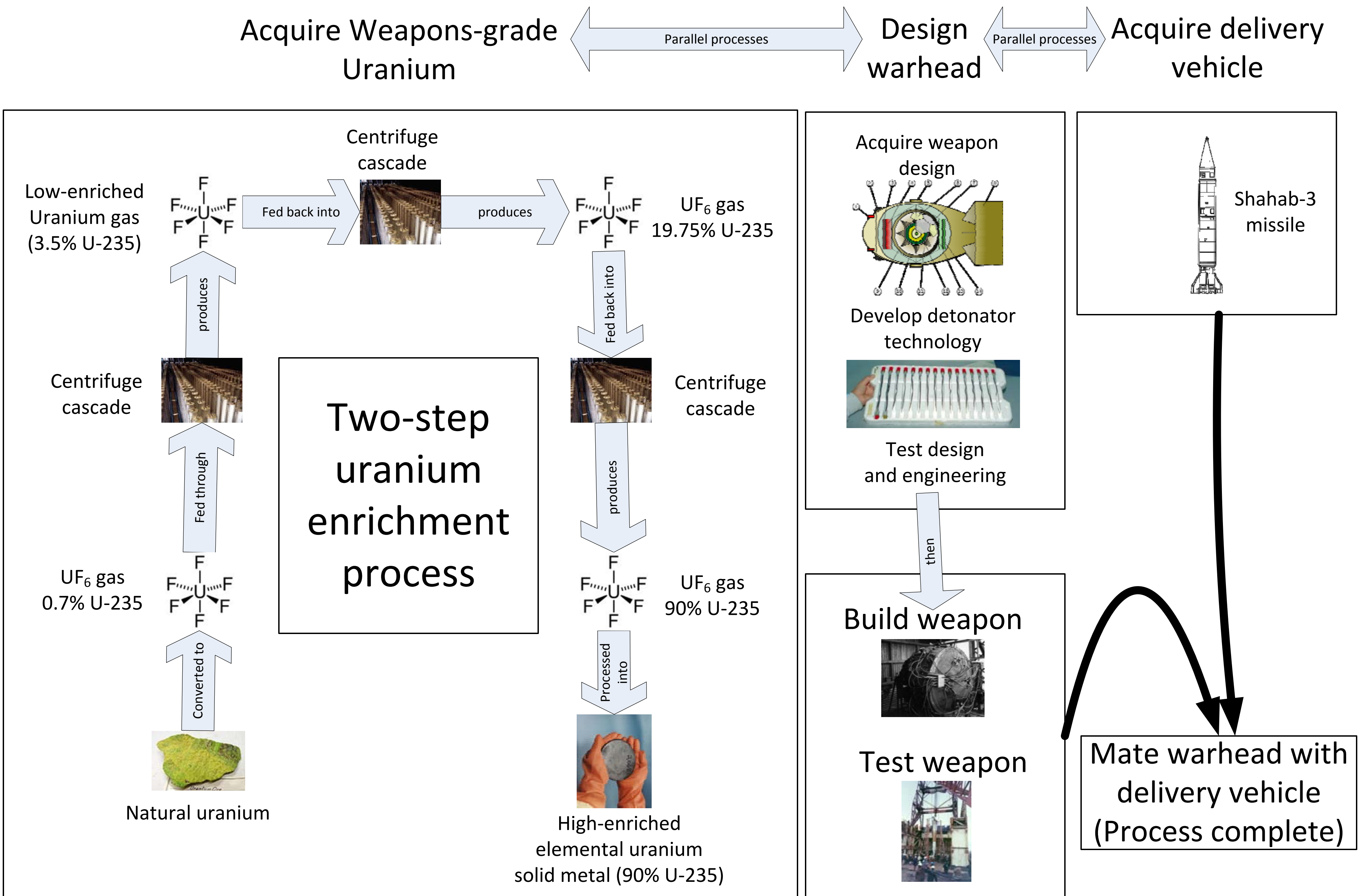
Assessment: Stuxnet derailed the 2009 Iranian effort to expand enrichment capability for roughly one year, but the enrichment expansion effort recovered in mid-2010 and continues on track. Direct actions have not had a visible effect on the enrichment program. Neither have sanctions. **Even the Stuxnet success does not appear to have derailed the steady growth of the Iranian 3.5% LEU stockpile**, however.



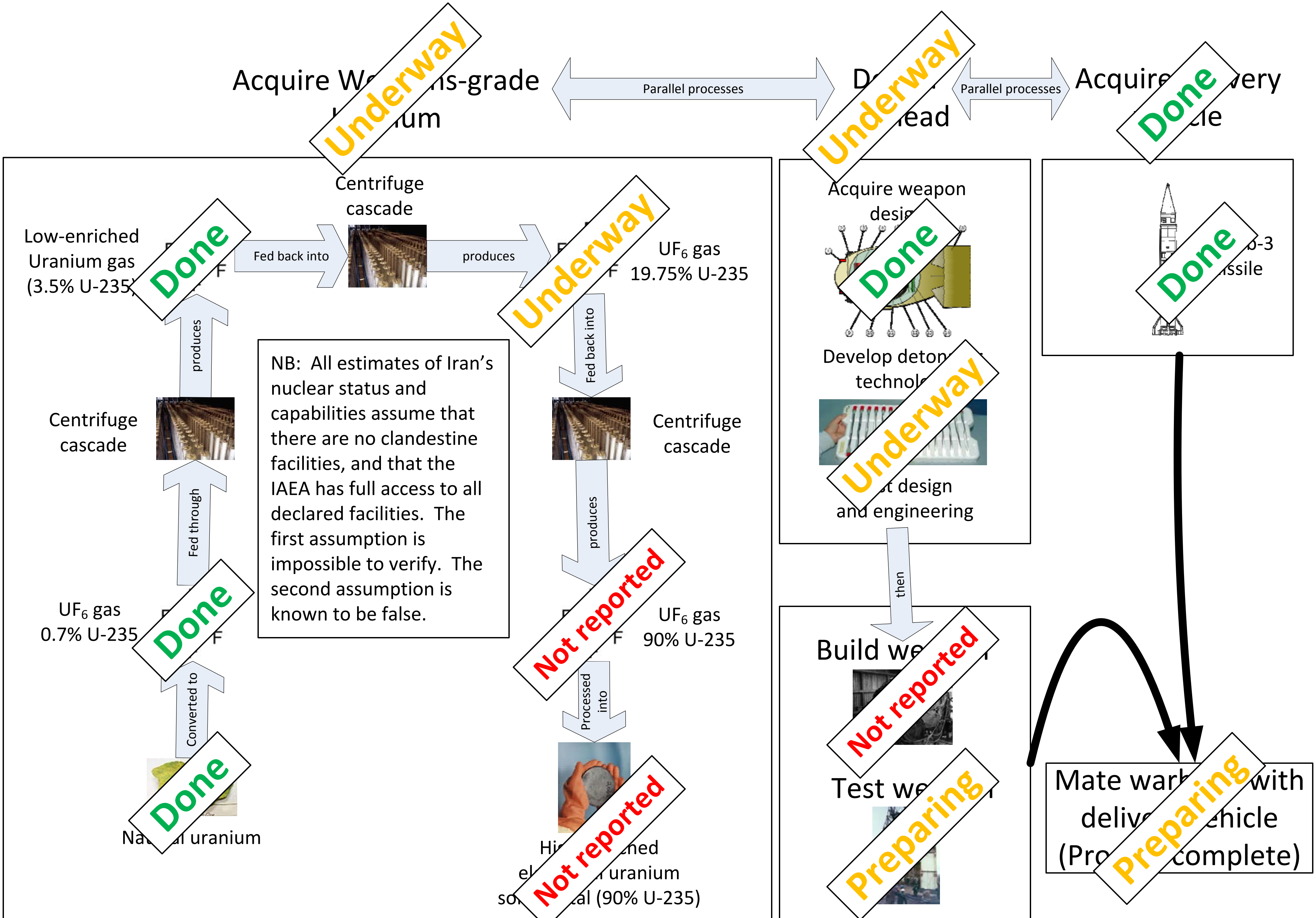
All nuclear data is from IAEA reports

Making an Atomic Bomb (Concept)

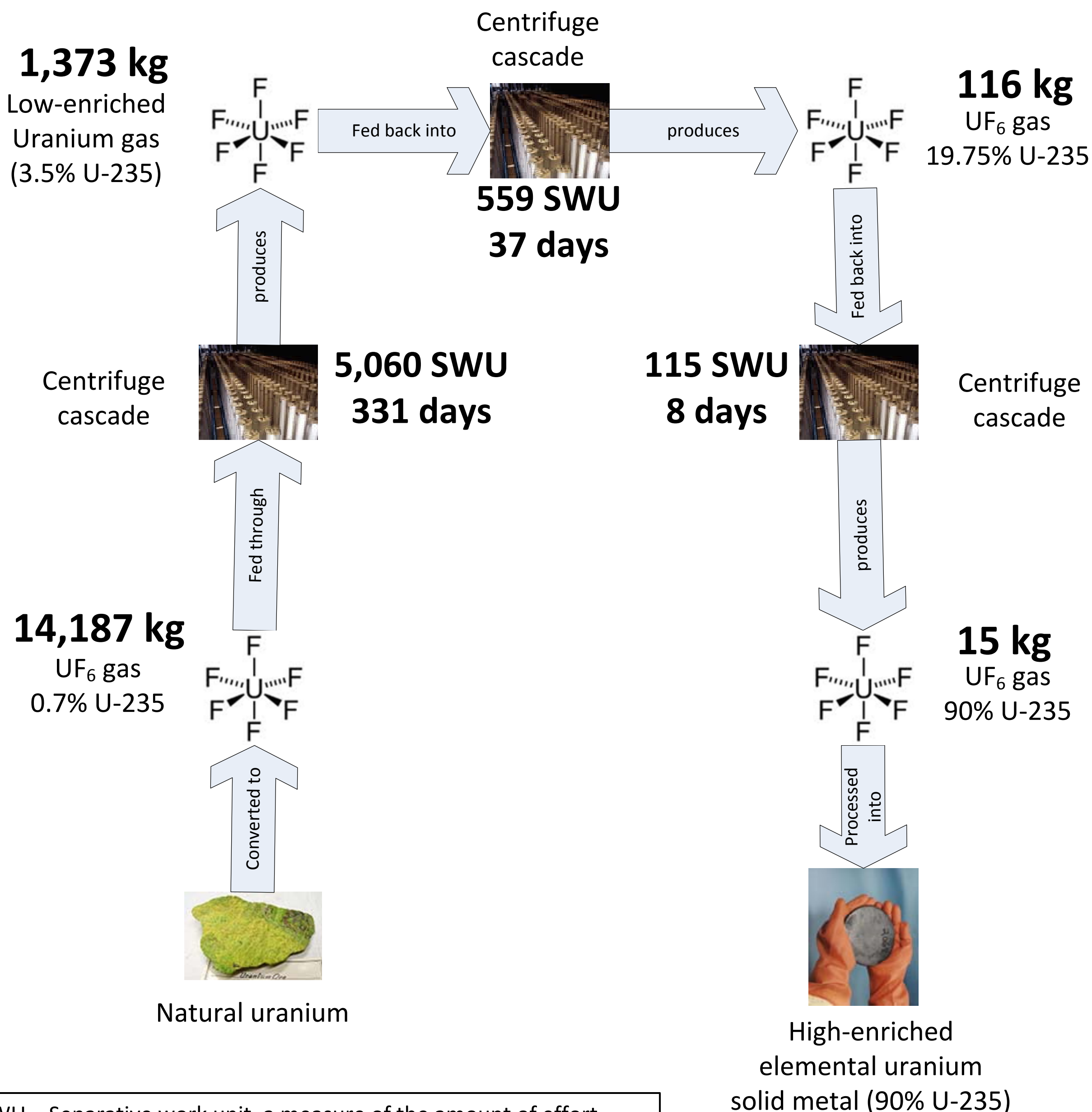
AEI CRITICALTHREATS.ORG
UNDERSTANDING THE CHALLENGE. TRACKING THE THREAT.



Making an Atomic Bomb (Status as of 18 NOV 2011)



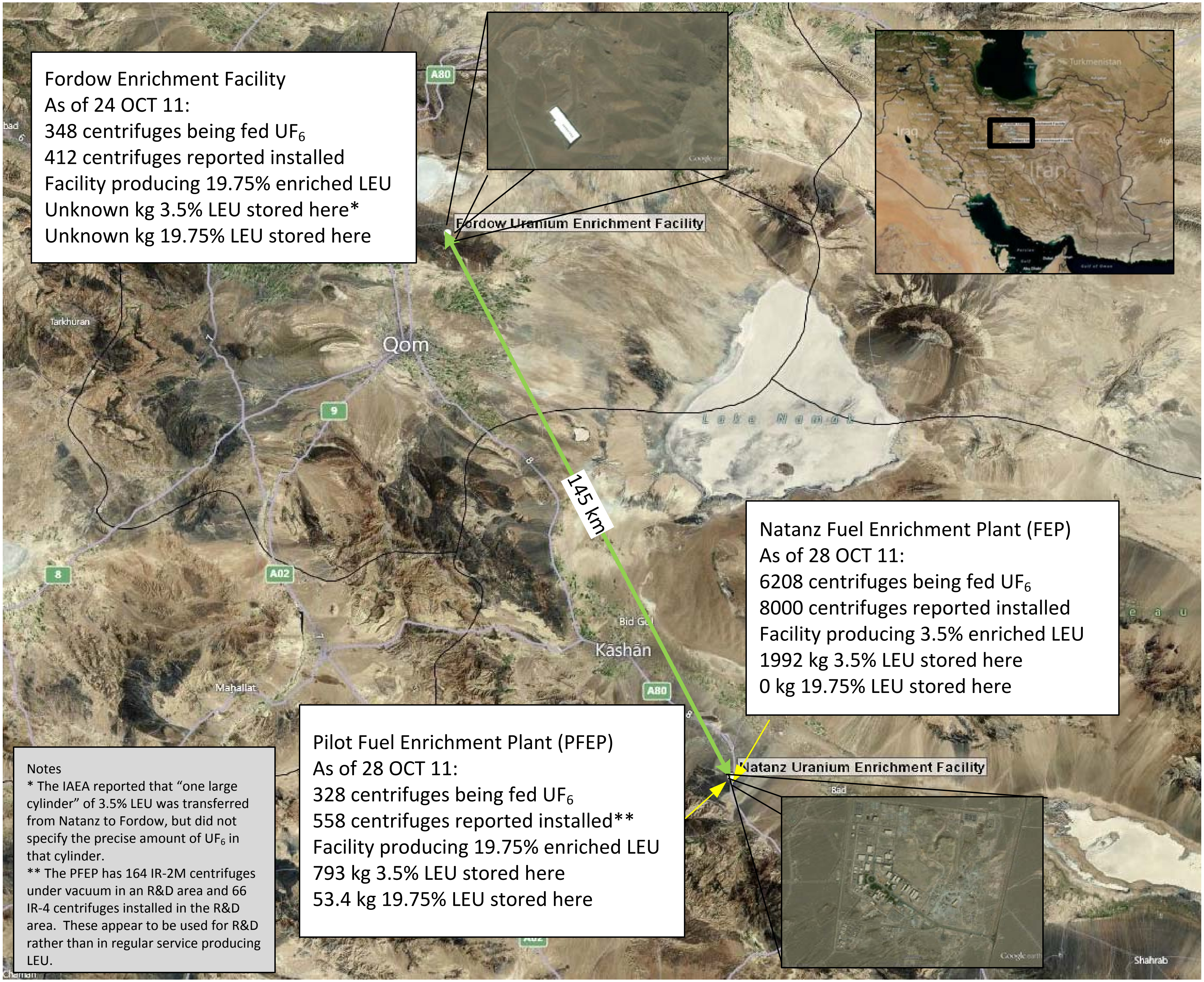
Why Enrichment Accelerates at Higher Concentration of U-235



The work and time required to enrich uranium from its natural concentration to 3.5% low-enriched uranium (LEU) is an order of magnitude greater than that required to enrich 20% LEU to weapons-grade concentrations (90% U-235). That is because centrifuges must spin more than 14,000 kg of uranium ore to produce 1,373 kg of 3.5% LEU, but only 116 kg of 20% LEU to produce 15 kg of weapons-grade uranium.

SWU = Separative work unit, a measure of the amount of effort required to process nuclear material. The SWU requirement is used to determine the time needed to enrich uranium with a given number of centrifuges operating at a given efficiency.

Iran’s Uranium Enrichment Facilities



Fordow Enrichment Facility
As of 24 OCT 11:
348 centrifuges being fed UF_6
412 centrifuges reported installed
Facility producing 19.75% enriched LEU
Unknown kg 3.5% LEU stored here*
Unknown kg 19.75% LEU stored here

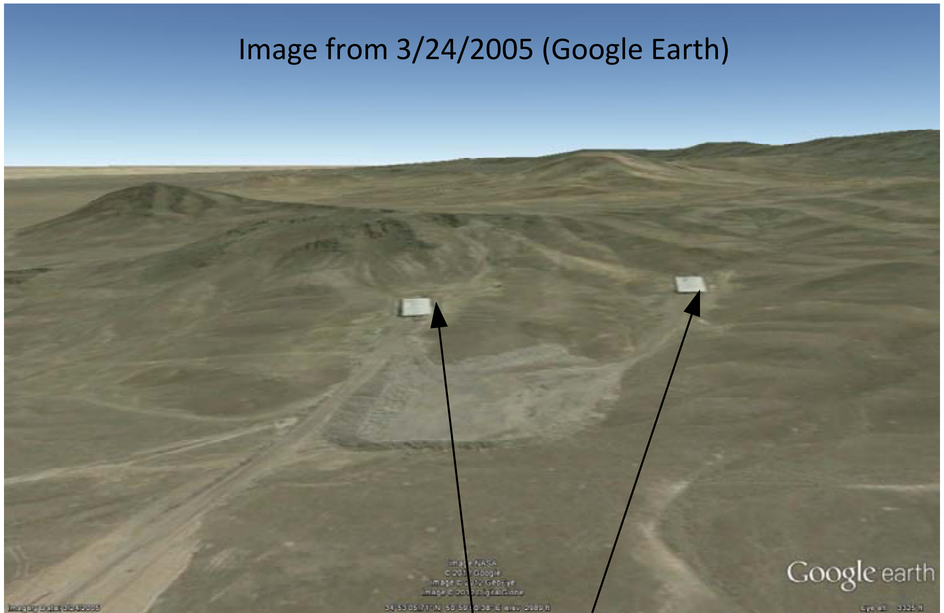
Natanz Fuel Enrichment Plant (FEP)
As of 28 OCT 11:
6208 centrifuges being fed UF_6
8000 centrifuges reported installed
Facility producing 3.5% enriched LEU
1992 kg 3.5% LEU stored here
0 kg 19.75% LEU stored here

Pilot Fuel Enrichment Plant (PFEP)
As of 28 OCT 11:
328 centrifuges being fed UF_6
558 centrifuges reported installed**
Facility producing 19.75% enriched LEU
793 kg 3.5% LEU stored here
53.4 kg 19.75% LEU stored here

Notes
* The IAEA reported that “one large cylinder” of 3.5% LEU was transferred from Natanz to Fordow, but did not specify the precise amount of UF_6 in that cylinder.
** The PFEP has 164 IR-2M centrifuges under vacuum in an R&D area and 66 IR-4 centrifuges installed in the R&D area. These appear to be used for R&D rather than in regular service producing LEU.

Construction and Capacity of Fordow Enrichment Facility

Image from 3/24/2005 (Google Earth)



Areas covered in 2005 appear as entrances to underground facilities in 2009

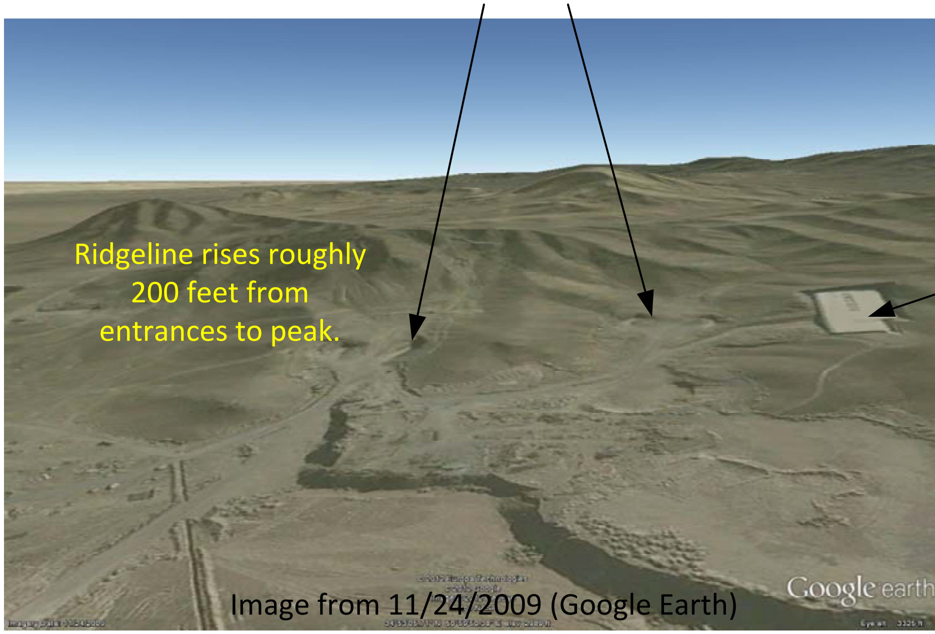


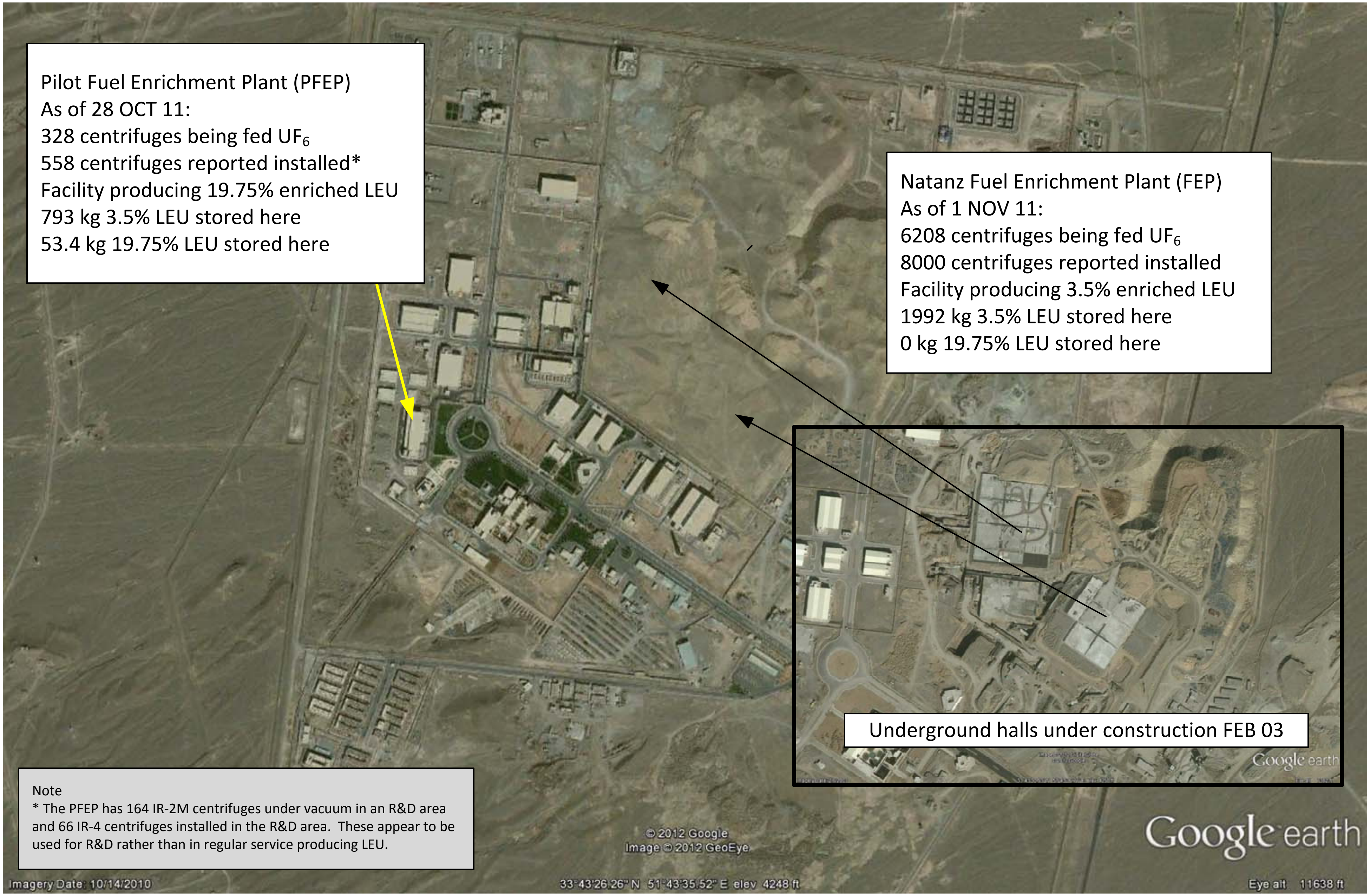
Image from 11/24/2009 (Google Earth)

New above-ground facility appears between 2005 and 2009

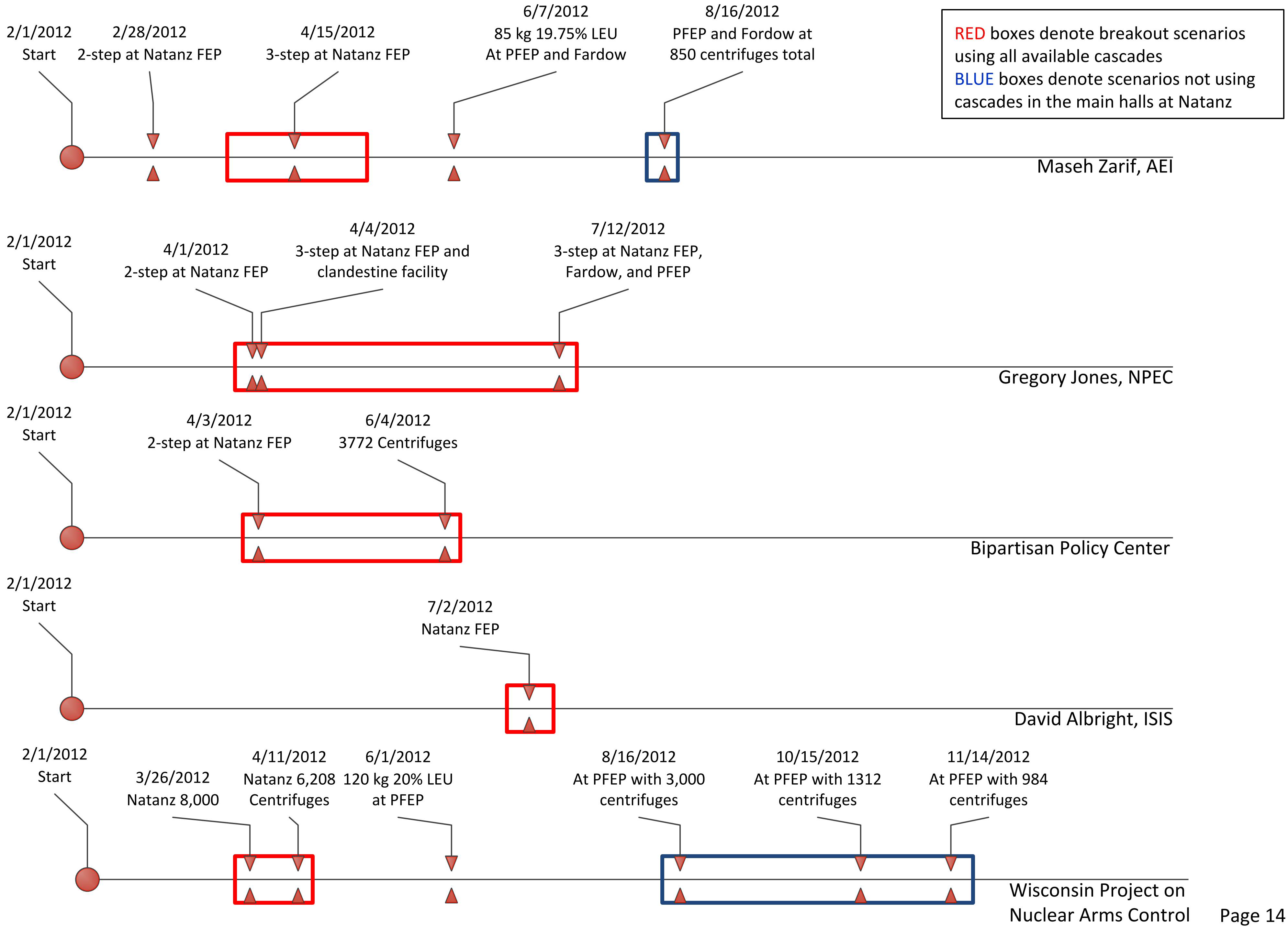
Fordow Enrichment Facility
As of 24 OCT 11:
348 centrifuges being fed UF_6
412 centrifuges reported installed
Facility producing 19.75% enriched LEU as of JAN 2012 (confirmed by IAEA)
Unknown kg 3.5% LEU stored here**
Unknown kg 19.75% LEU stored here

Note
** The IAEA reported that “one large cylinder” of 3.5% LEU was transferred from Natanz to Fordow, but did not specify the precise amount of UF_6 in that cylinder.

Natanz Enrichment Facilities



Comparison of Estimated Breakout Times



Sources

International Atomic Energy Agency (IAEA) – The IAEA publishes quarterly reports on Iran's nuclear program and enrichment progress. Enriched uranium stockpile, centrifuge count, potential inspection windows, and other technical data provided by the IAEA are used in our analysis to determine historical rates of production and to serve as a basis for building projections. IAEA reports on Iran are available at http://www.iaea.org/newscenter/focus/iaeairan/iaea_reports.shtml.

World Information Service Project on Energy (WISE) – WISE provides a uranium enrichment calculator for calculating the separative work required to achieve specific levels of U-235 concentration. The calculator uses manual inputs of feed, product, and tails figures to calculate separative work units (SWU). The resultant SWU serves as the basis for calculating time requirements. This assessment uses the WISE calculator to determine the SWU required for enriching at various levels. The online calculator is accessible at http://www.wise-uranium.org/nfcue.html.

Gregory Jones, Nonproliferation Education Policy Center (NPEC) – Gregory Jones provided the estimated tails percentage figures for enriching to weapons-grade uranium levels for two-step and three-step batch recycling methods (starting with 3.5% LEU) at the Natanz FEP and two-step batch recycling (from 3.5%) at Natanz PFEP/Fordow FEP, where cascades are interconnected. Jones has written that the technical assumption underlying an Iranian attempt to break out using two-step batch recycling without reconfiguration (from 3.5%) may not be feasible. The alternative Iranian breakout approach he suggests, adding an intermediary step between 19.75% and 90% enrichment, is one that we have relied on in our analysis. Jones's analyses are available at http://www.npolicy.org/.

Institute for Science and International Security (ISIS) – ISIS has contributed to a technical debate among experts regarding the feasibility of two-step and three-step batch recycling methods. ISIS analyses are available at http://isis-online.org/.

Alexander Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation," *Science and Global Security* (16:1-25, 2008) – Glaser's analysis of the P-1 centrifuge—the foundation of Iran's IR-1 centrifuge program—is the basis for two-step batch recycling projections for enriching to weapons-grade uranium. A key aspect of Glaser's analysis in this paper was that 90% HEU can be produced in one step from 19.7% LEU without the need to reconfigure the arrangement of cascades. In October 2011, according to Gregory Jones, Glaser said he had "been made aware of certain phenomena that are not taken into account" in his 2008 analysis and that "We now find that the most credible scenarios involve some kind of cascade reconfiguration." See Greg Jones, "Earliest Date Possible for Iran's First Bomb," Nonproliferation Education Policy Center, December 6, 2011, http://npolicy.org/article.php?aid=1124&rid=4. For Glaser's original analysis, see http://www.princeton.edu/sgs/publications/sgs/archive/16-1-Glaser.pdf.

International Commission on Nuclear Non-Proliferation and Disarmament (ICCND) – The ICCND notes that a basic implosion-type nuclear weapon design with an explosive yield of 15 kilotons would require 15 kg of weapons-grade uranium. We use this figure as the minimum 90% HEU Iran would produce to fuel one bomb. See http://icnnd.org/Reference/reports/ent/part-ii-4.html.

Thomas B. Cochran and Christopher E. Paine, "The Amount of Plutonium and Highly-Enriched Uranium Needed for Pure Fission Nuclear Weapons," National Resources Defense Council, April 13, 1995. – Cochran and Paine assert that the "significant quantity" measurement of 25 kg weapons-grade HEU used by the IAEA greatly overestimates the amount of fissile material required to fuel a basic implosion-type nuclear explosive device. They estimate that a state with a low technical capability can produce a bomb with an explosive yield of 20 kilotons with 16 kg weapons-grade HEU. See: http://www.nrdc.org/nuclear/fissionw/fissionweapons.pdf.