The Iranian Nuclear Program

Timelines, Data, and Estimates

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Version 2.0, 27 FEB 2012

Current as of 27 FEB 2012 using data from IAEA report dated 24 FEB 2012

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 MAY 2012 IAEA Report *(assuming data measured on 4 MAY 2012)*

Note: The IAEA measures enriched uranium in gaseous form (hexafluoride). This assessment uses solid (elemental) uranium; 1 kg of gaseous uranium is equal to 0.67 kg of solid uranium.

3.5% LEU	MAY 2012 (est.)	FEB 2012 (actual)	Change	Confidence
IR-1 centrifuges producing/being fed at FEP:	9,139	8,808	+331	low
LEU produced at Natanz (elemental uranium):	3,974 kg	3,652 kg	+322 kg	moderate
19.75% LEU				
IR-1 centrifuges producing/being fed at PFEP:	328	328	0	high
IR-1 centrifuges producing/being fed at FFEP:	696	696	0	moderate
LEU produced at Natanz PFEP and Fordow FEP:	102.5 kg	73.1 kg	+29.4 kg	moderate
HEU (60% or 90%) at declared facilities	none	none	0	high
Centrifuges enriching				
IR-1	10,163	9,832	+331	low
IR-2*	164	164	0	low
IR-4*	0	0	0	high

*The IAEA reported that Iran is feeding smaller numbers of advanced centrifuges at PFEP but is not withdrawing LEU from those machines.

Key Points

Iran is developing a rapid nuclear weapons breakout capability. Its expanding uranium enrichment activities at Natanz and Fordow are reducing the time it would need to break out and produce fuel for an atomic weapon.

Iran is increasing its total stockpile of uranium enriched up to 20%—which can be converted to weapons-grade levels of 90% in a short amount of time—at the Natanz Pilot Fuel Enrichment Plant (PFEP) and, now, at the buried Fordow Fuel Enrichment Plant (FFEP) where it began producing that material in December 2011. It has taken steps to prepare for a further expansion of the FFEP by building the infrastructure required to install and operate over two thousand additional centrifuges.

It is also increasing its stockpile of uranium enriched around the 3.5% level; that material is the feedstock for producing uranium enriched to 20%. During the past reporting period, Iran sharply increased the number of centrifuges being fed natural uranium gas for the production of 3.5% fuel and began installing equipment to operate several thousand additional centrifuges at the large Natanz Fuel Enrichment Plant (FEP).

We assess that Iran, continuing to operate PFEP and FFEP under the current conditions described by the International Atomic Energy Agency, will have 85 kilograms of uranium enriched up to 20% in April 2012. This amount will be enough for Iran to produce 15 kg of weapons-grade uranium for one bomb within 3 months using the more-efficient interconnected cascades installed at FFEP for the final enrichment step to 90%. A more immediate breakout scenario, in which Iran races to produce additional material enriched to 20% at FEP and then enriches to 90% there in its operational centrifuges, would result in a drastically shorter timeline for Iran's acquisition of bomb fuel.

Projected Versus Actual Data

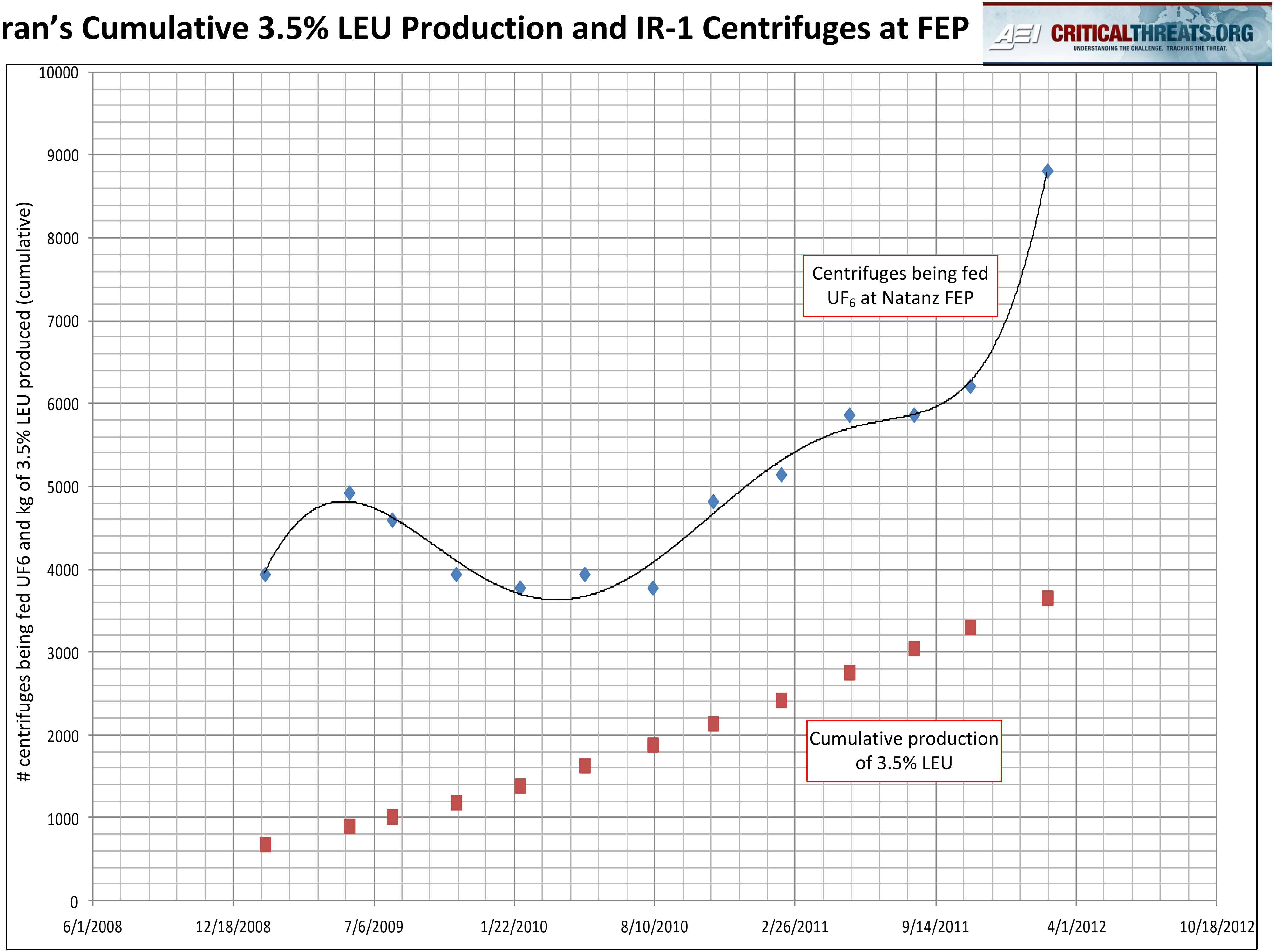
3.5% LEU – We previously estimated that Iran would be enriching in 6720 IR-1 centrifuges (low confidence) and would have produced an additional 403 kg of uranium enriched to 3.5% (moderate confidence) at the Natanz Fuel Enrichment Plant (FEP) in the current reporting period. The IAEA reported that Iran is feeding 8808 centrifuges and produced 354 kg of 3.5% enriched uranium at FEP during the reporting period. **This represents a more than 40% increase in the number of centrifuges being fed with UF_6 at FEP.** Iran has also installed 6177 empty IR-1 centrifuge casings at FEP. **Our estimate of the 3.5% LEU stockpile was off by 2.5%. We have recalibrated our estimations based on this error, and the new methodology is the basis for the estimates on Slide 2.**

19.75% LEU – We previously estimated that Iran would be enriching in 328 IR-1 centrifuges at PFEP (high confidence) and in 348 IR-1 centrifuges at the Fordow Fuel Enrichment Plant (high confidence). The IAEA report confirmed the former estimate; however, in the latter case, Iran installed and began feeding two additional cascades of 348 total IR-1 centrifuges at FFEP in late January 2012. Iran is now operating a total of 6 IR-1 cascades (1024 total centrifuges) configured in 3 sets of 2 interconnected cascades at these two facilities. The IAEA confirmed that Iran also has prepared to further expand its enrichment capacity at Fordow by putting into place the infrastructure for housing 2088 additional IR-1 centrifuges.

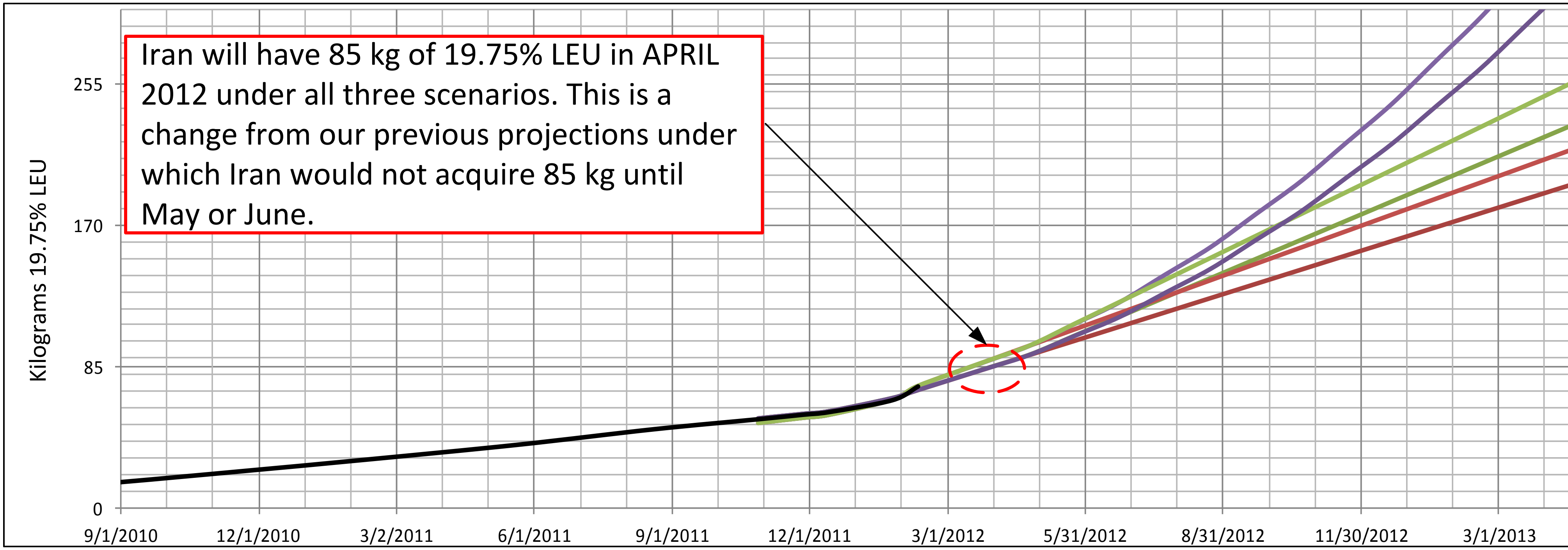
We previously estimated that Iran would have produced 64 kg of uranium enriched up to 20% by this reporting period. The actual figure reported by the IAEA was 73.1 kg. Of this amount, 9.2 kg is stockpiled at FFEP and about 5 kilograms was converted to U_3O_8. **The significant error in this estimate resulted from the unexpectedly-rapid production increase at Fordow.**

Self-Evaluation: We assess that our methods for estimating 19.75% and 3.5% LEU stockpiles are valid and accurate (and we are improving them as new data emerges). We have been less successful at estimating the Iranian ability and intent to bring new cascades on line and are not optimistic that we will be able to improve our ability to make such estimates.

Iran's Cumulative 3.5% LEU Production and IR-1 Centrifuges at FEP



Iran's Historical and Projected 19.75% LEU Stockpile at PFEP/FFEP



**The two lines for each scenario represent a range of projected values based on different calculations of demonstrated centrifuge efficiency.*

Scenarios

1) **RED**. Iran enriches to 19.75% with 2 cascades totaling 328 IR-1 centrifuges at the Natanz PFEP and 4 cascades totaling 696 IR-1 centrifuges at Fordow. **This scenario reflects the current situation reported by the IAEA in FEB 2012.**

2) **GREEN**. Same as Scenario 1, but in late APR 2012, Iran begins operating 2 additional cascades of 174 IR-1 centrifuges (348 total) alongside the 4 already operating at Fordow and continues enriching in the 2 cascades of IR-1 centrifuges (328 total) at the Natanz PFEP. **This scenario assumes that Iran will install 2 additional cascades at Fordow in the next two months.**

3) **PURPLE**. Same as Scenario 2, but in late JUN 2012 Iran begins operating two additional cascades of IR-1 centrifuges (348 total) at Fordow every two months until that facility is at its declared capacity of 16 cascades of IR-1 centrifuges (2784 total). Iran continues enriching at the two cascades at Natanz PFEP. **Iran will reach maximum capacity at Fordow in February 2013 under this scenario.**

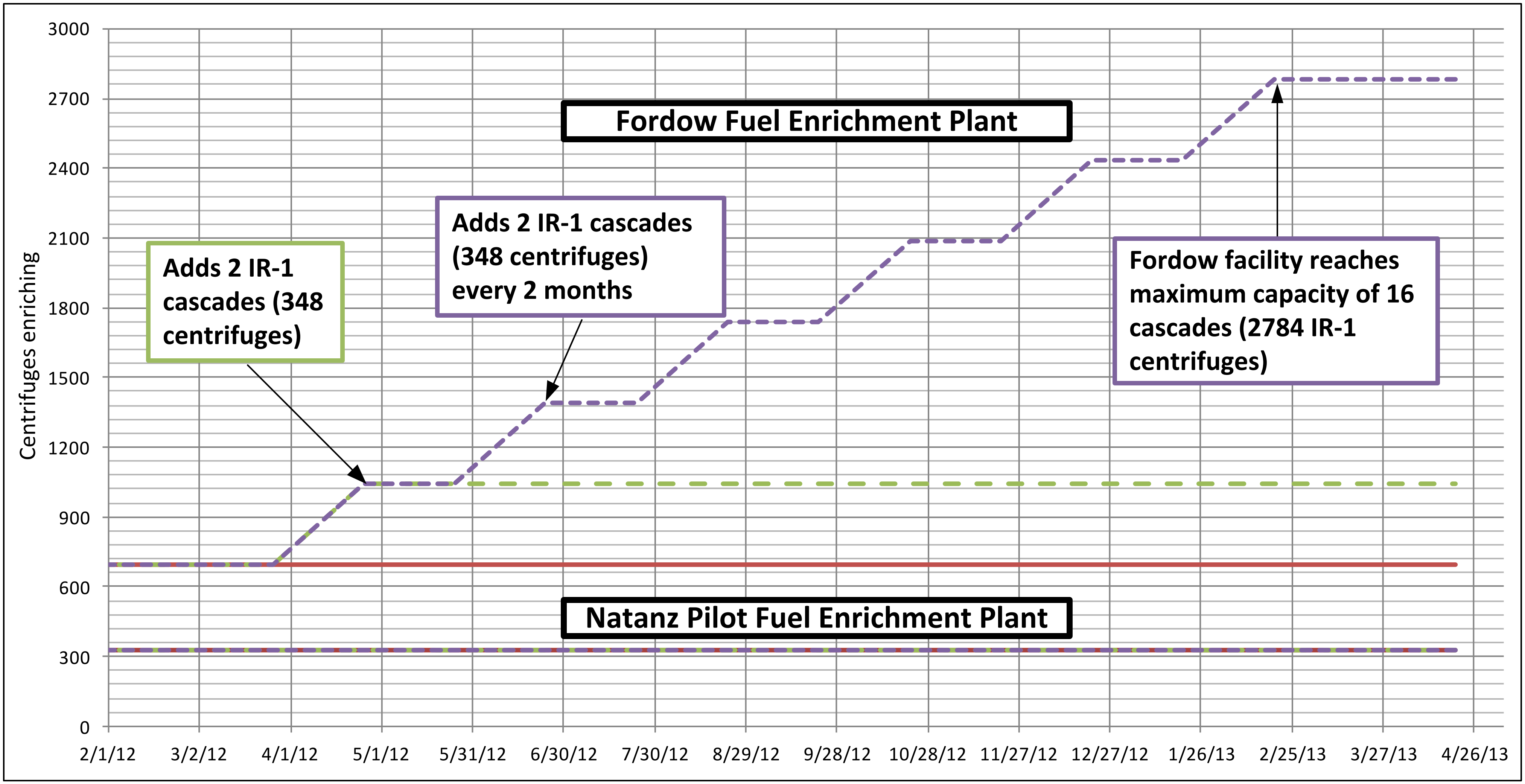
These estimates are based on demonstrated enrichment efficiency at Iran's nuclear facilities. The small size of the data set introduces error into the estimates that should in principle decrease over time. But the efficiency of Iran's operations certainly fluctuates, so the error in these estimates is unlikely to approach zero asymptotically. The higher estimate here weights efficiency over the most recent period more heavily; the lower estimate weights the historical average more heavily. Both estimates have been below actual recorded Iranian production at almost every data point.

Projected Location/Number of Centrifuges Enriching to 19.75% LEU

RED – Scenario 1 (current situation as described in February 2012 IAEA report)

GREEN – Scenario 2 (same as 1 plus addition of two IR-1 cascades [348 centrifuges] in late April)

PURPLE – Scenario 3 (same as 2 plus addition of two IR-1 cascades [348 centrifuges] every two months)



Iran Nuclear Timeline

Worst-Case and Most Likely Case Breakout Scenarios

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

Assessment

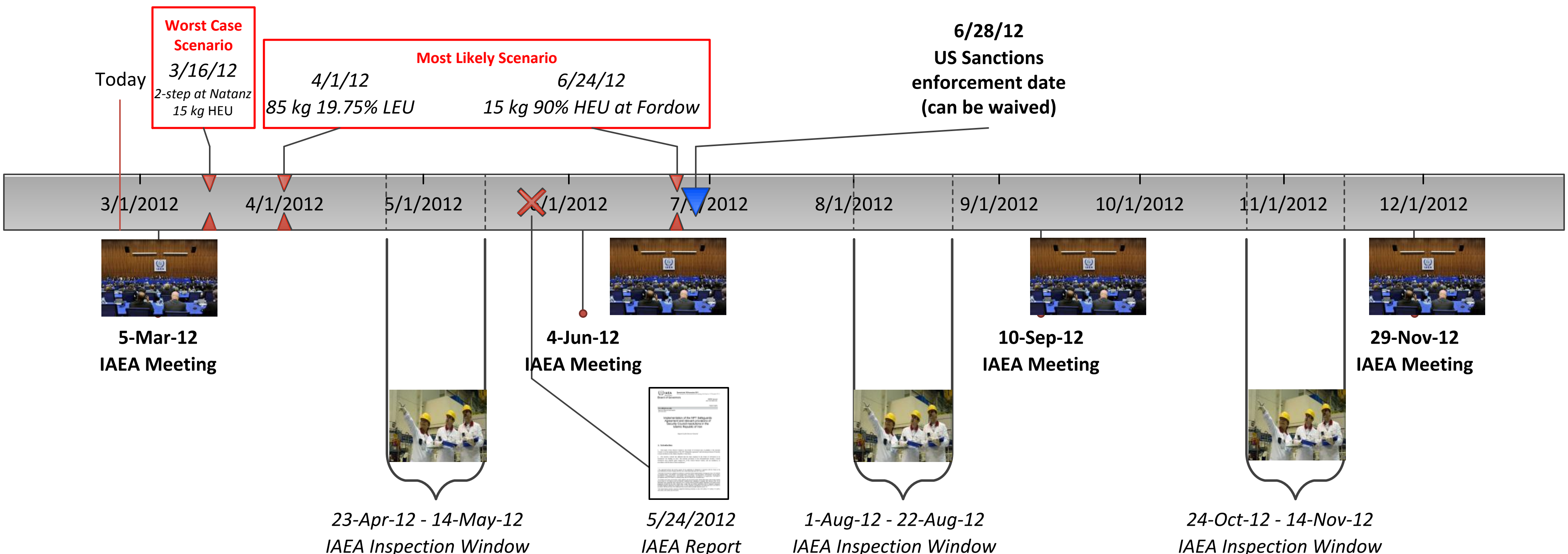
Iran COULD acquire enough weapons-grade uranium for one weapon within **THREE WEEKS** of starting to race at Natanz, **under certain contested technical assumptions**. This breakout timeline has shrunk in the last few months given an increase of centrifuges at Natanz and a growing stockpile of uranium enriched up to 20%. This worst-case scenario is **HIGHLY UNLIKELY**.

Iran WILL acquire enough 19.75% enriched uranium by **APR 2012** to be within **3 MONTHS** of producing weapons-grade uranium for one 15 kiloton bomb at the Fordow facility. This breakout scenario is **MOST LIKELY**. The breakout window has moved to the left in recent months given Iran's increased production and stockpiling of 19.75% enriched uranium, which is now occurring at both the Fordow and Natanz facilities.

See the next two pages for the facts and assumptions underlying these estimates.

Current as of 27 FEB 2012 using data from IAEA report dated 24 FEB 2012

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



Breakout Scenarios

Worst-case

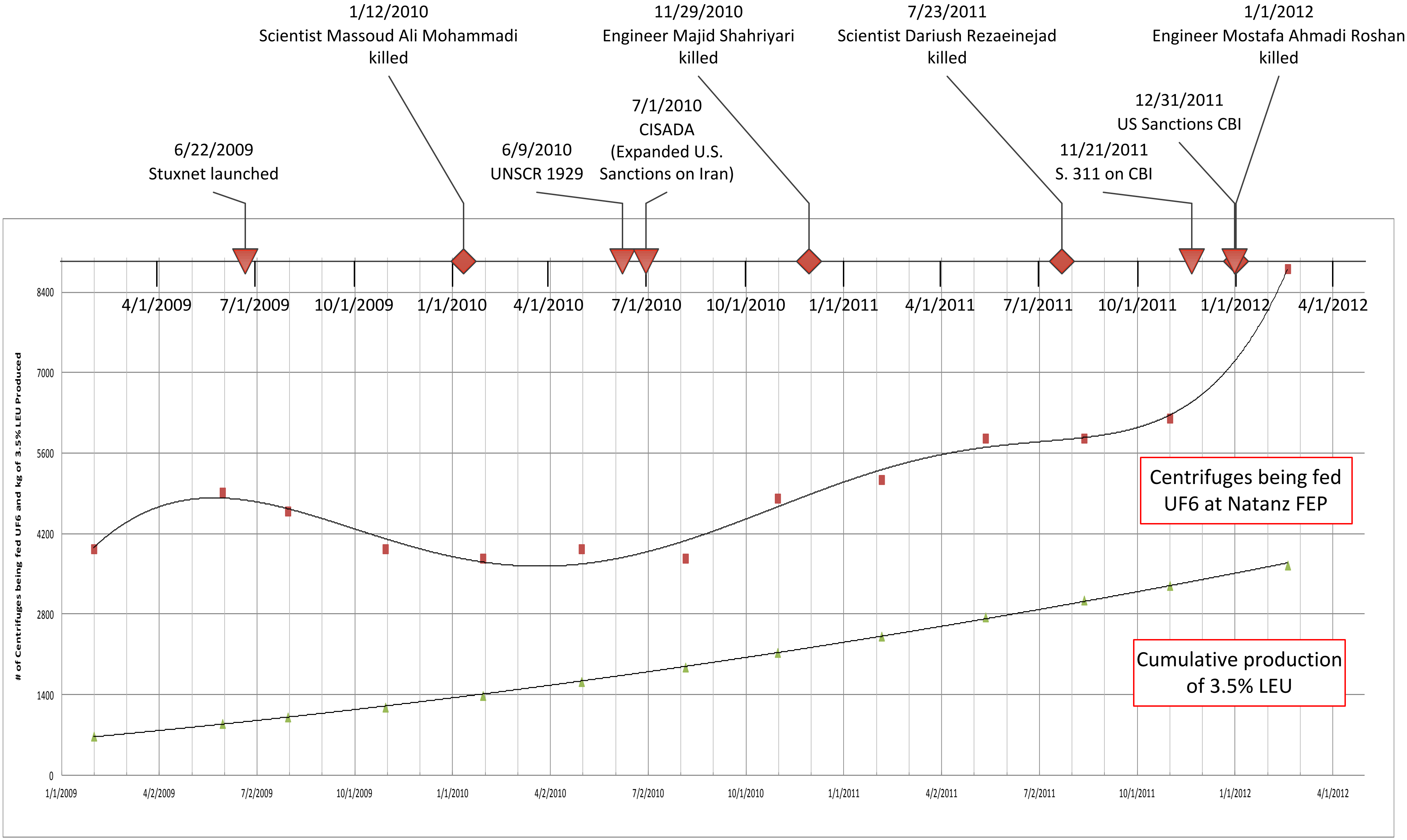
- The worst-case scenarios assume that Iran devotes all operational centrifuges at Natanz (as of 19 FEB 2012) to producing first additional 19.75% LEU and then 90% HEU, ceasing production of 3.5% LEU. Such actions would be visible to inspectors and so would most likely occur between inspections. Iranian nuclear policy and strategy does not appear to be going down this road.
- The scenarios assume 8,808 centrifuges spinning (the number being fed uranium as of 19 FEB 2011) operating with an efficiency of 0.9 separative work units (SWU)/centrifuge/year (roughly the efficiency they have demonstrated).
- Iran begins to race to breakout on 1 MAR, producing 116 kg of 19.75% LEU and then enriching directly to 90% HEU
- If Iran breaks out using a three-step process, it would need to produce 243 kg of 19.75% LEU in total, then enrich to 60% HEU and then to 90% HEU. Using this three-step process, Iran could acquire fuel for one weapon in 1.5 months.
- *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 (see Sources page). These data are derived from the Natanz facility; the Fordow installations are notably more efficient with lower tails assays.*

Most Likely

- The 8,808 centrifuges being fed in the main cascade hall at Natanz continue to produce 3.5% LEU and are not diverted to higher-level enrichment. Iran continues enriching to 19.75% until it has amassed approximately 85 kg 19.75% LEU, which can yield 15 kg 90% HEU.
- Enrichment to 19.75% occurs in four cascades totaling 696 IR-1 centrifuges at Fordow (2 sets of 2 interconnected cascades) and two cascades totaling 328 IR-1 centrifuges at the Natanz PFEP.
- Enrichment from 19.75% to 90% occurs in the four cascades at Fordow in one step using a tails assay of 4.6%. *The difference in the tails between the worst-case and most likely breakout scenarios reflects the fact that the cascades at Fordow, like the ones at Natanz PFEP, are interconnected in pairs.*

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.

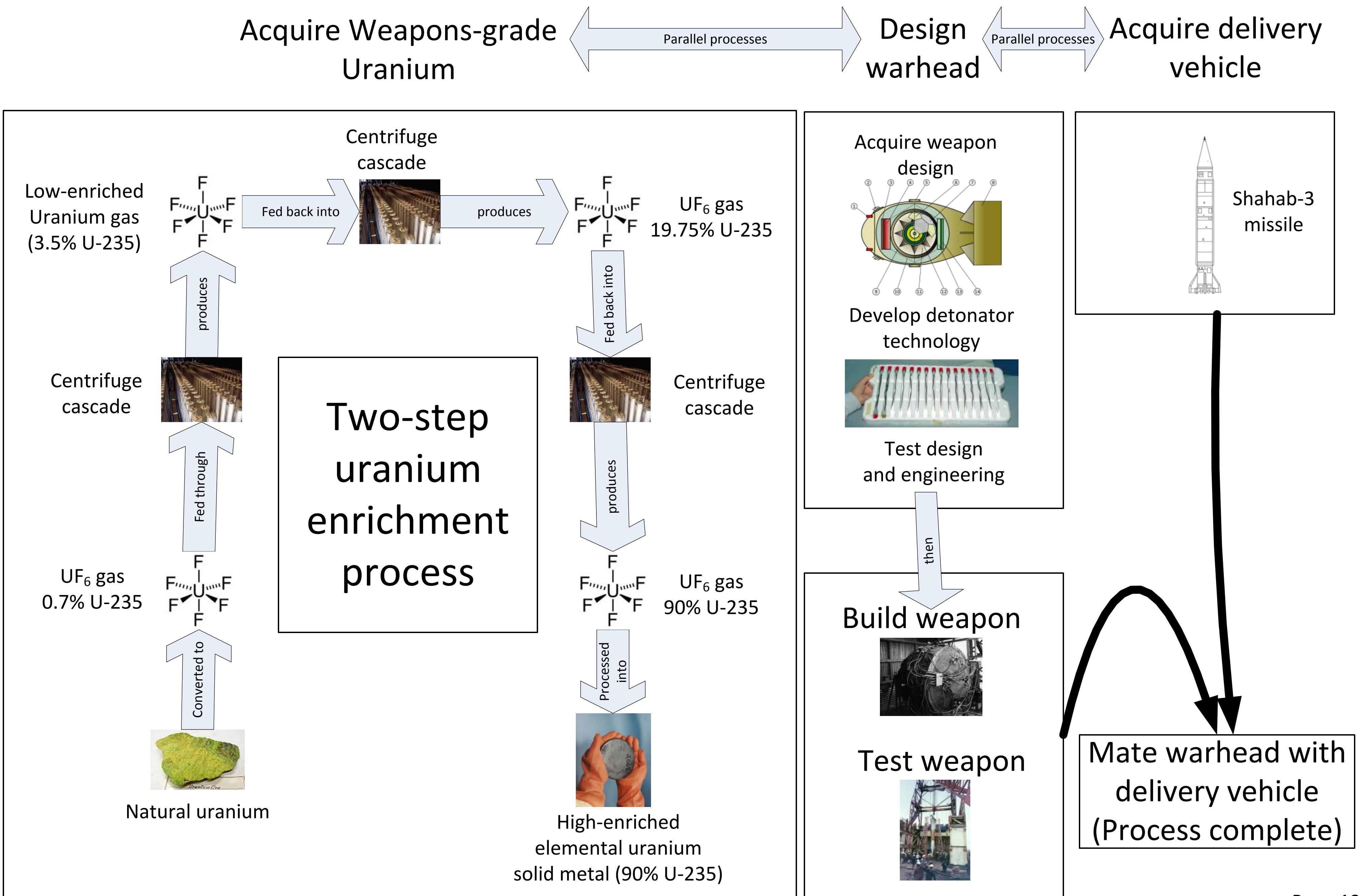


All nuclear data is from IAEA reports

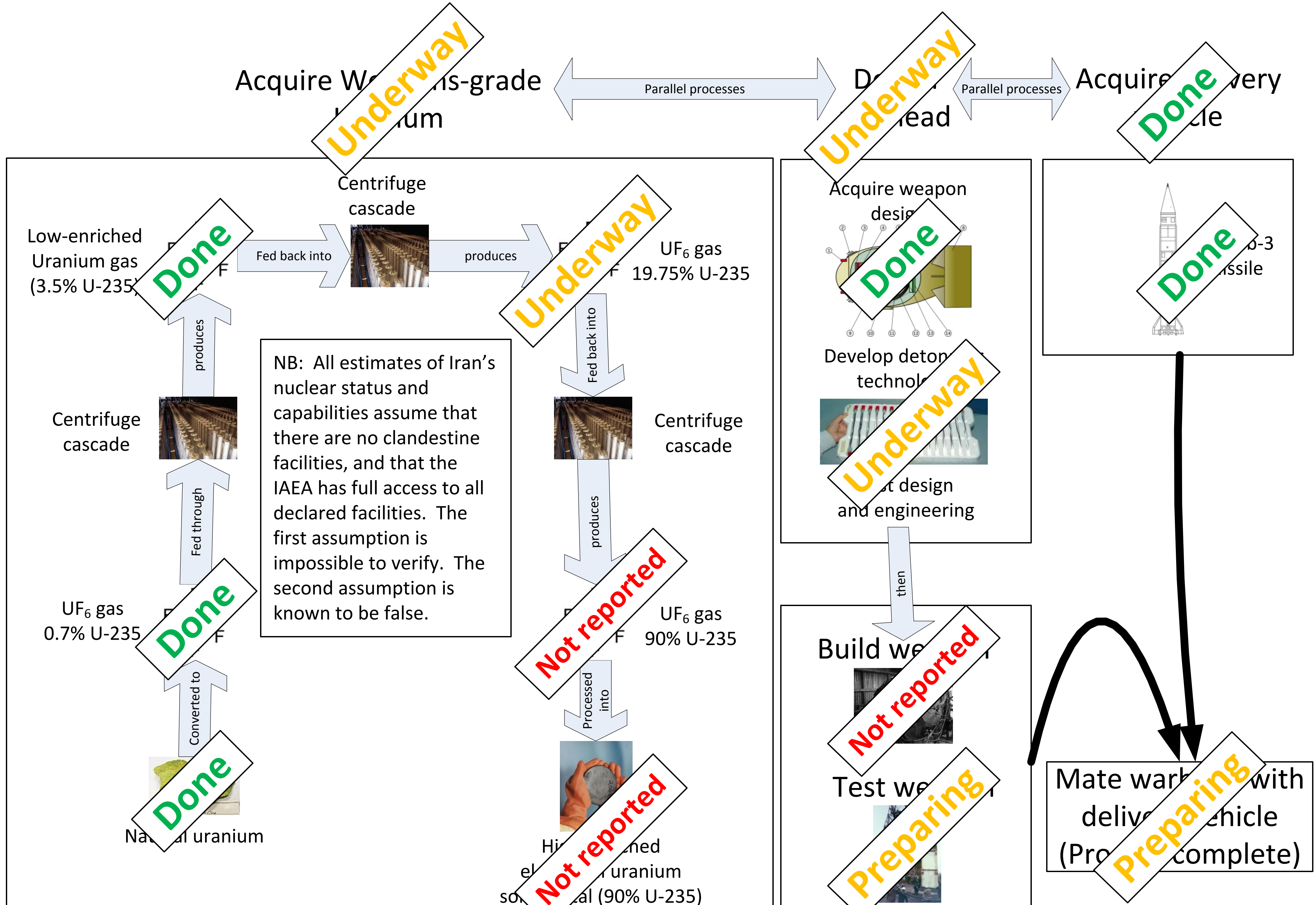
Atomic Weapons Data

- 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).
- 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.

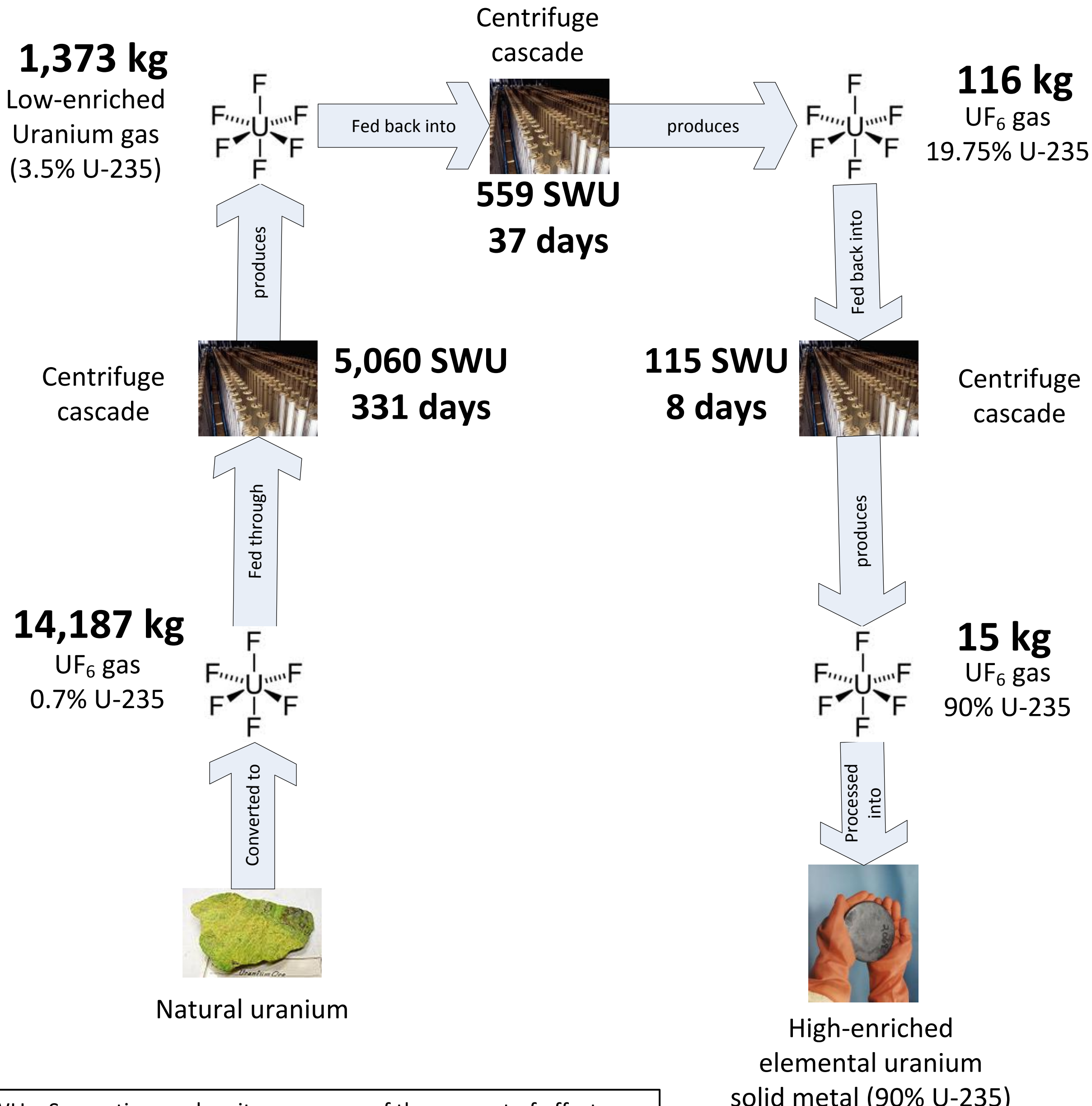
Making an Atomic Bomb (Concept)



Making an Atomic Bomb (Status as of 8 FEB 2012)



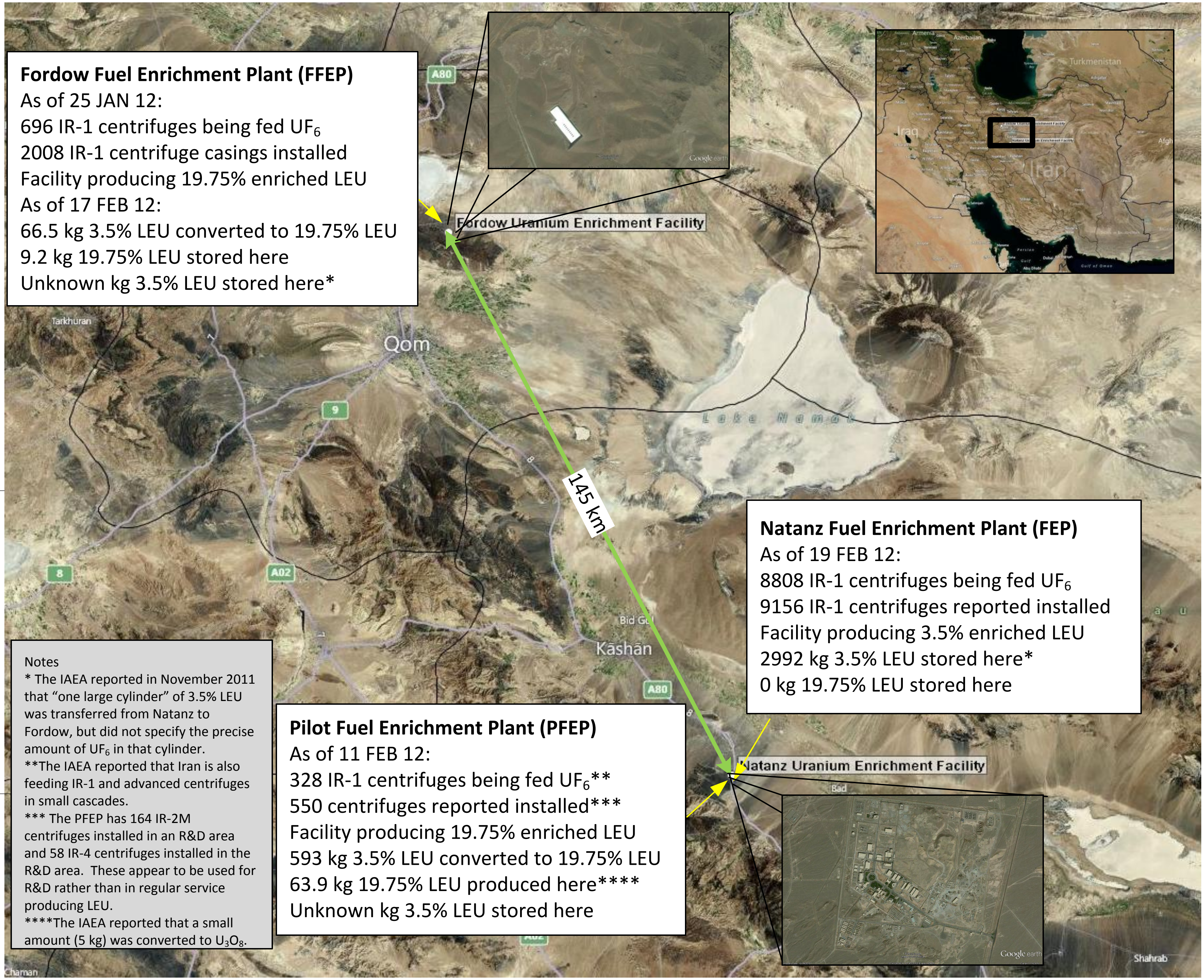
Why Enrichment Accelerates at Higher Concentration of U-235



The work and time required to enrich uranium from its natural concentration (0.7%) 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



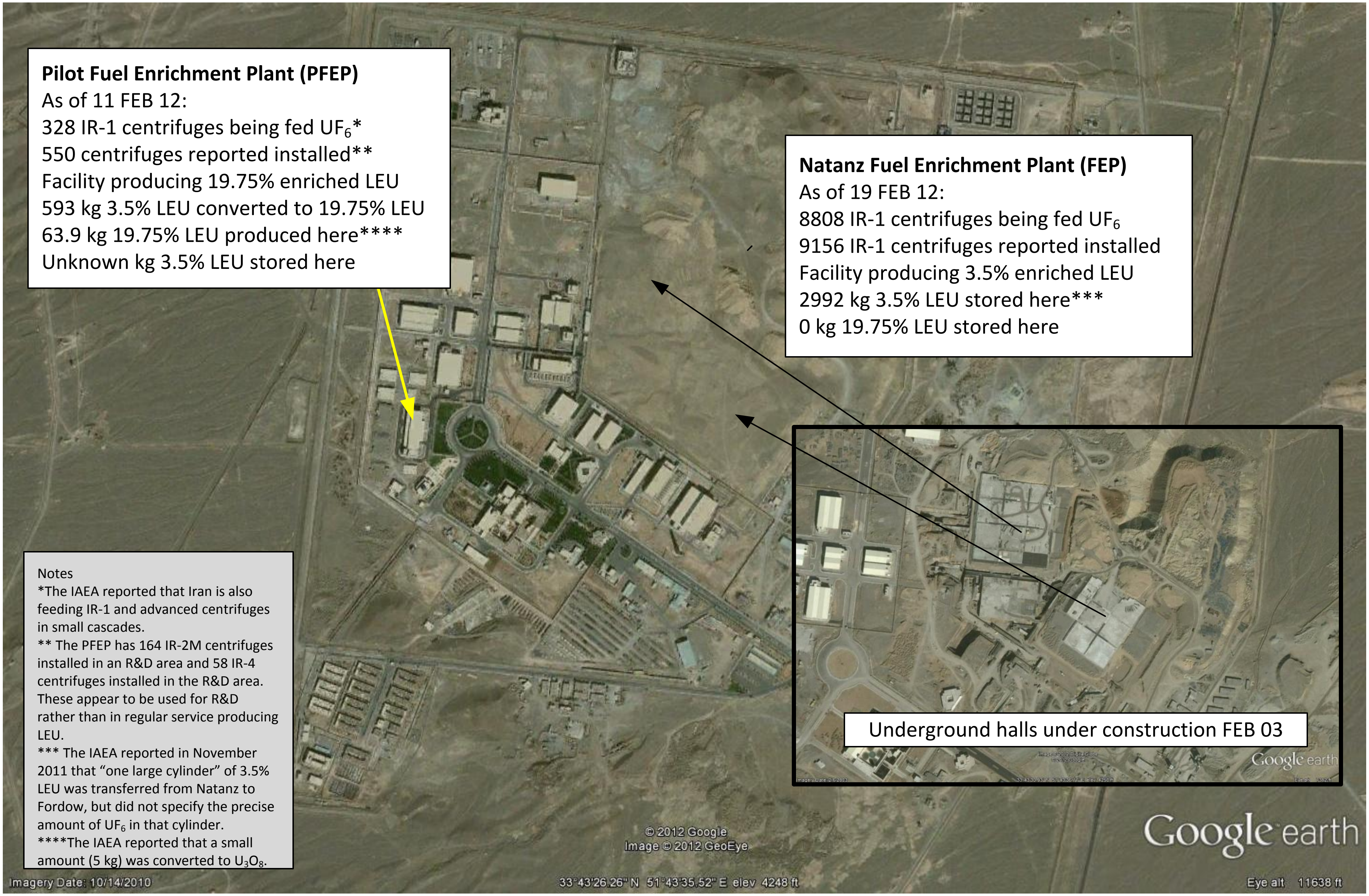
Fordow Fuel Enrichment Plant (FFEP)
As of 25 JAN 12:
696 IR-1 centrifuges being fed UF_6
2008 IR-1 centrifuge casings installed
Facility producing 19.75% enriched LEU
As of 17 FEB 12:
66.5 kg 3.5% LEU converted to 19.75% LEU
9.2 kg 19.75% LEU stored here
Unknown kg 3.5% LEU stored here*

Natanz Fuel Enrichment Plant (FEP)
As of 19 FEB 12:
8808 IR-1 centrifuges being fed UF_6
9156 IR-1 centrifuges reported installed
Facility producing 3.5% enriched LEU
2992 kg 3.5% LEU stored here*
0 kg 19.75% LEU stored here

Pilot Fuel Enrichment Plant (PFEP)
As of 11 FEB 12:
328 IR-1 centrifuges being fed UF_6**
550 centrifuges reported installed***
Facility producing 19.75% enriched LEU
593 kg 3.5% LEU converted to 19.75% LEU
63.9 kg 19.75% LEU produced here****
Unknown kg 3.5% LEU stored here

Notes
* The IAEA reported in November 2011 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 IAEA reported that Iran is also feeding IR-1 and advanced centrifuges in small cascades.
*** The PFEP has 164 IR-2M centrifuges installed in an R&D area and 58 IR-4 centrifuges installed in the R&D area. These appear to be used for R&D rather than in regular service producing LEU.
****The IAEA reported that a small amount (5 kg) was converted to U_3O_8.

Natanz Enrichment Facilities



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Construction and Capacity of Fordow Enrichment Facility

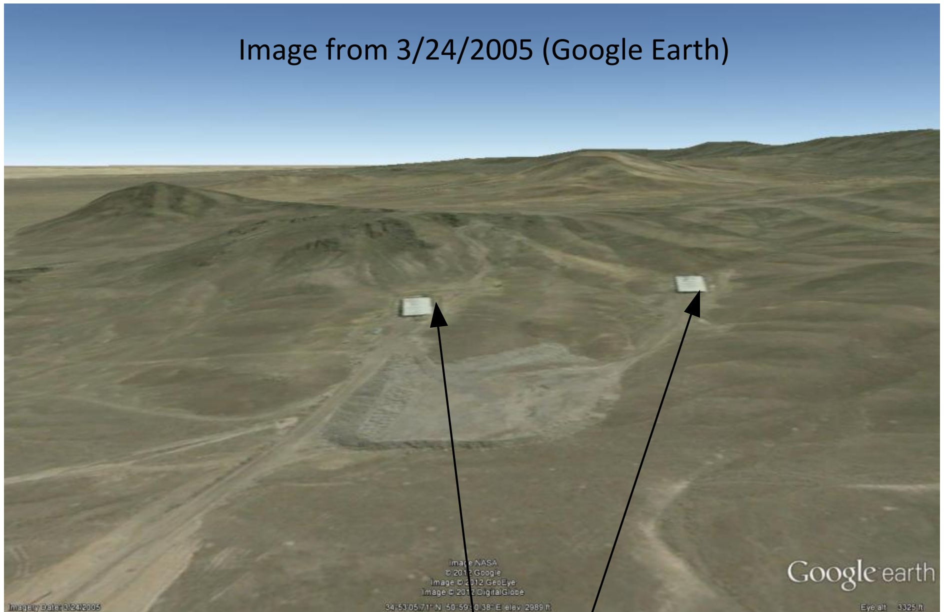

Image from 3/24/2005 (Google Earth)

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

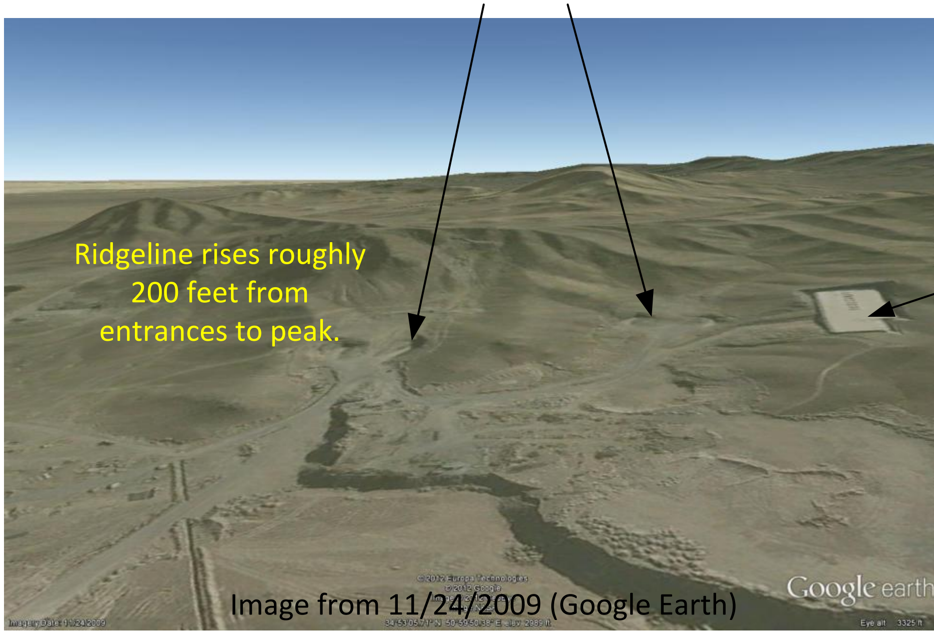

Image from 11/24/2009 (Google Earth)

New above-ground facility appears between 2005 and 2009

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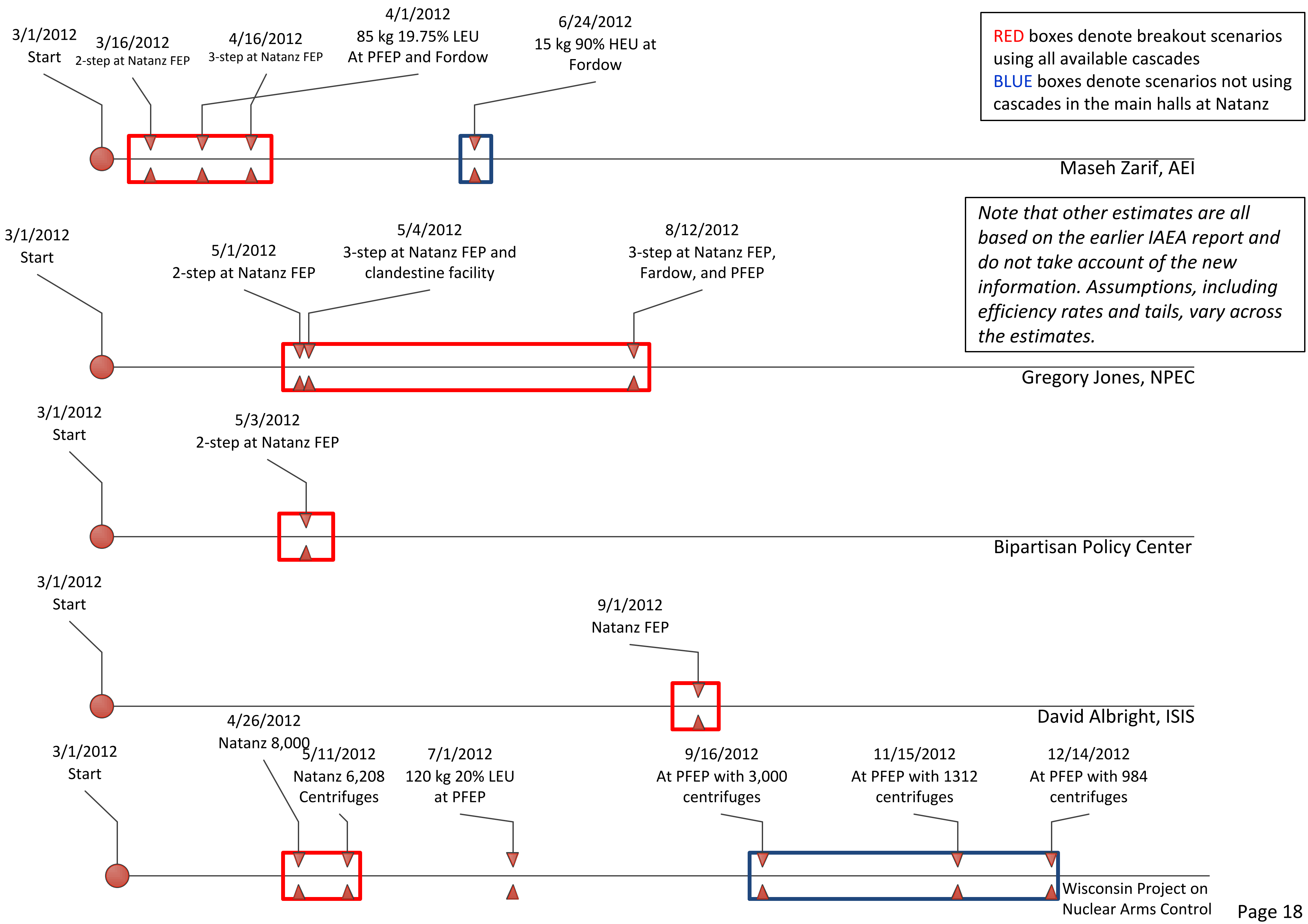
Comparison of Estimated Breakout Times



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.