# Technical Aspects of the Iran Nuclear Agreement

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# Outline of Talk

- Paths to a Bomb
  - Uranium
  - Plutonium
- Breakout and Sneakout
- The Joint Comprehensive Plan of Action

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# IAEA: SQ ≡ "Significant Quantity"

"The approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded."

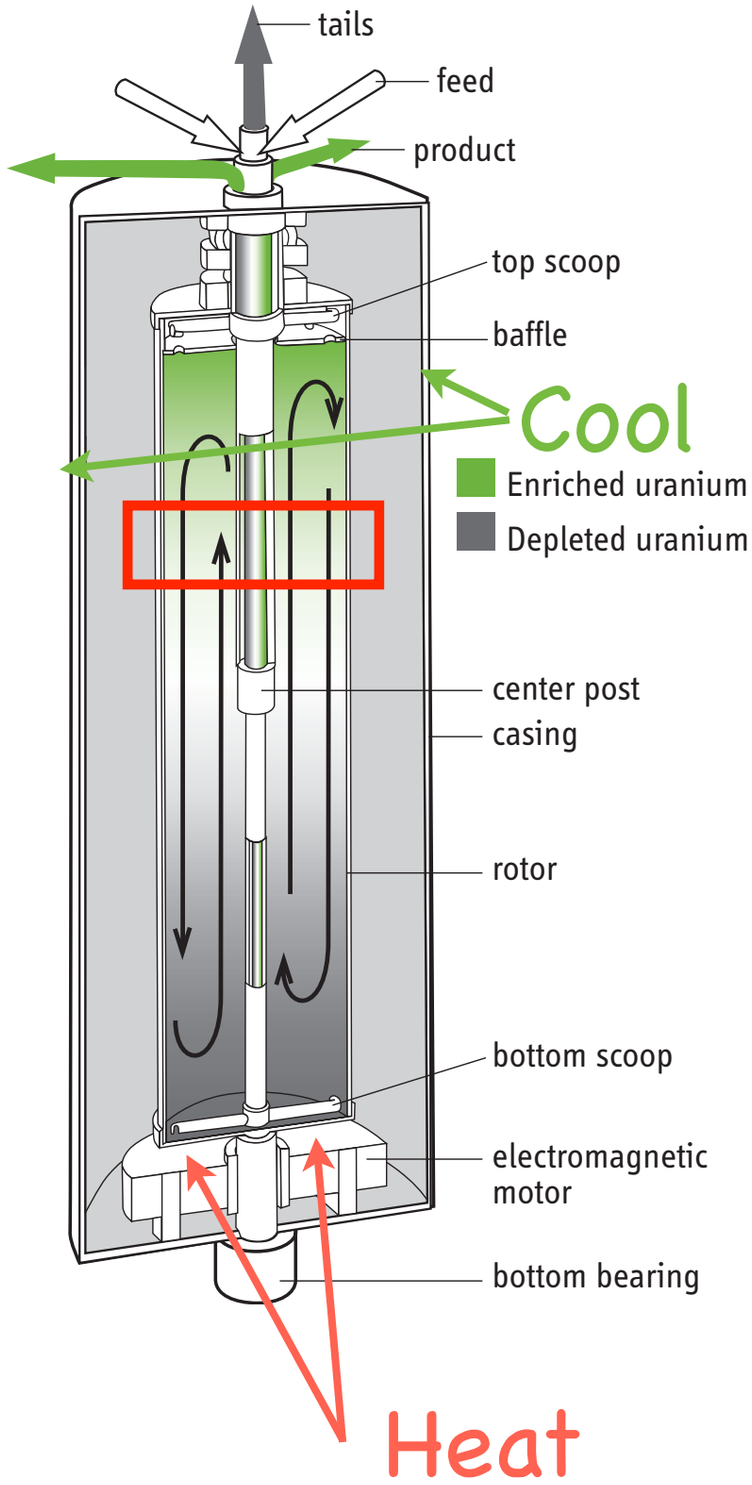
| Material | SQ |
|---|---|
| Highly Enriched Uranium ($\geq$20% $^{235}U$) | 25 kg contained $^{235}U$ |
| Plutonium (any composition with < 80% $^{238}Pu$) | 8 kg |

# Uranium Path to One Weapon

- **Mining – Extract U ore from ground**
  **~ 4000 t uranium ore ~ 0.2% U**
- **Milling – Crush ore and extract $U_3O_8$ (Yellowcake)**
  **8t U in 9.4t $U_3O_8$**
- **Conversion – Convert $U_3O_8$ to $UF_6$ gas**
  **8t U in 11.8t $UF_6$ gas (source of confusion)**
- **Enrichment: 0.7% $^{235}U$ + 99.3% $^{238}U$**
  **→ 90% $^{235}U$ + 10% $^{238}U$**
  **27.8 kg Highly Enriched Uranium (HEU)**
- **Convert to metal, machine to precise shape**

# Gas Centrifuge Enrichment

- **Centrifugal force pushes $^{238}U$ out more than $^{235}U$**
- **The Trick: Circulating flow lets this happen continuously during a vertical transit**
- **Scoops collect a little extra $^{235}U$ on the top, a little extra $^{238}U$ on the bottom**

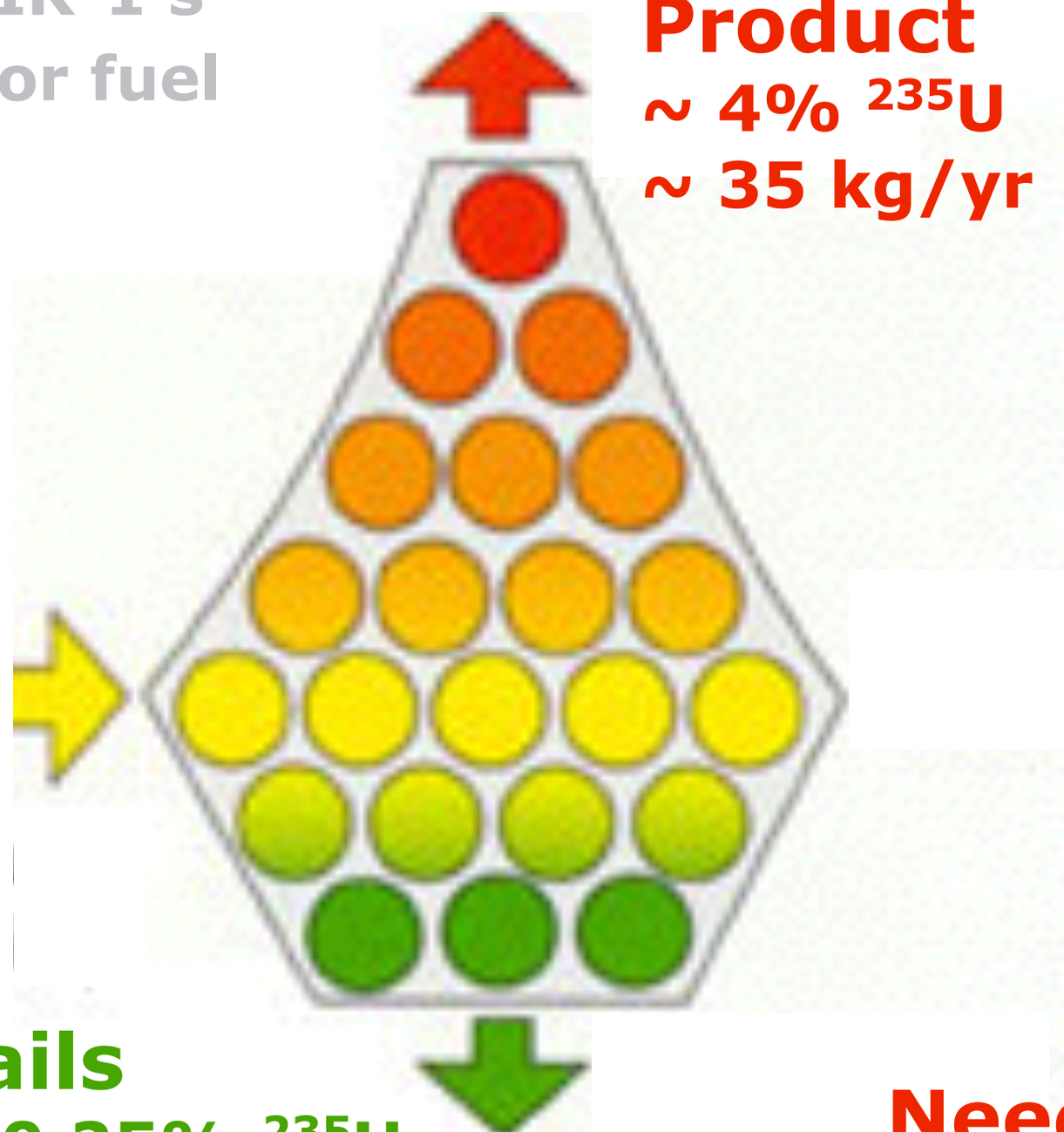


# It Takes Lots of Centrifuges to Fuel Power Plants

# Centrifuges are Hooked up into Cascades to make Reactor Fuel

1 cascade of IR-1's making reactor fuel

**Product**
~ 4% $^{235}U$
~ 35 kg/yr



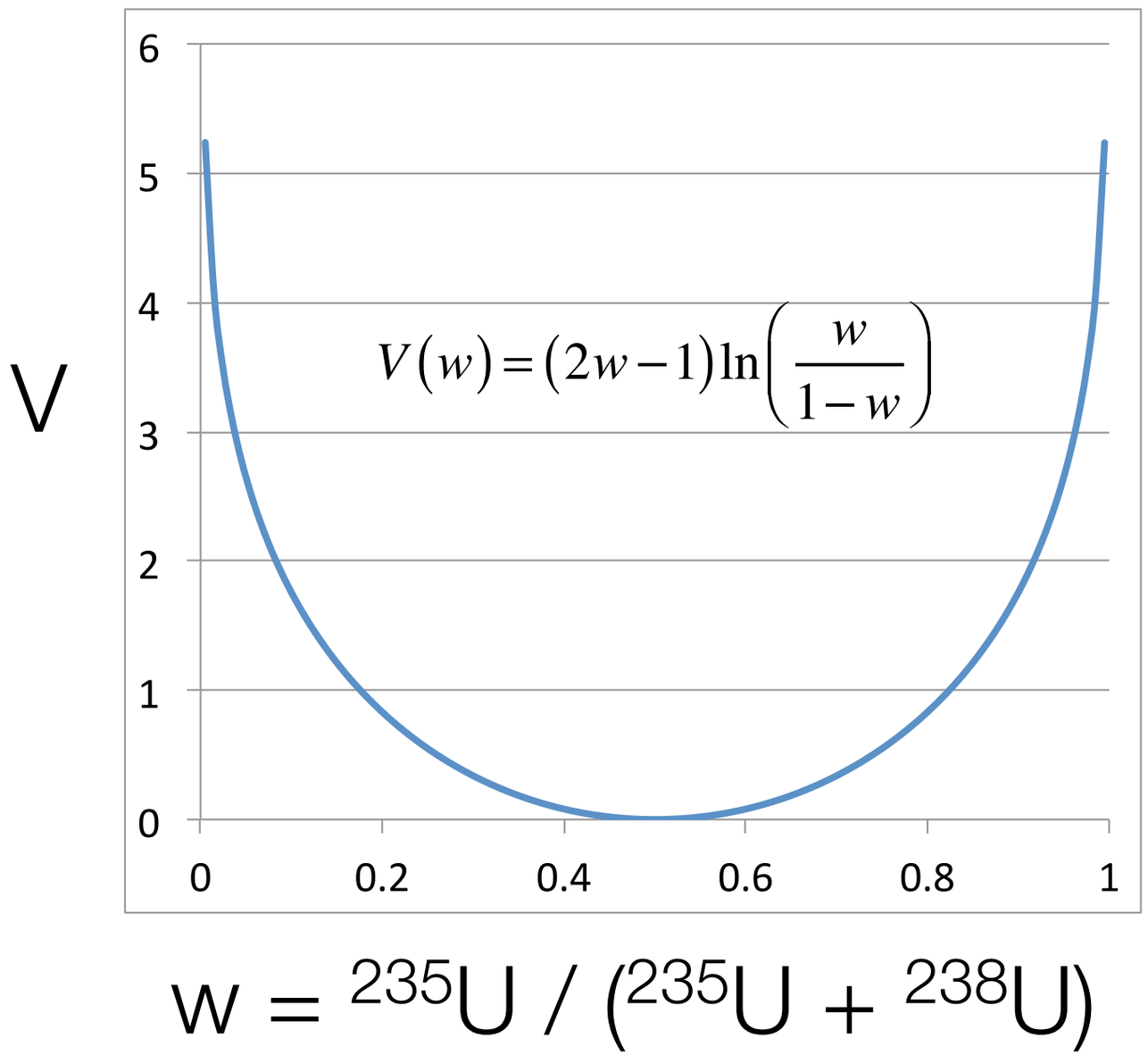
~ 15 stages
~ 175 centrifuges

**Feed**
Natural Uranium:
0.7% $^{235}U$
~ 410 kg/yr

**Tails**
~ 0.25% $^{235}U$
~ 375 kg/yr

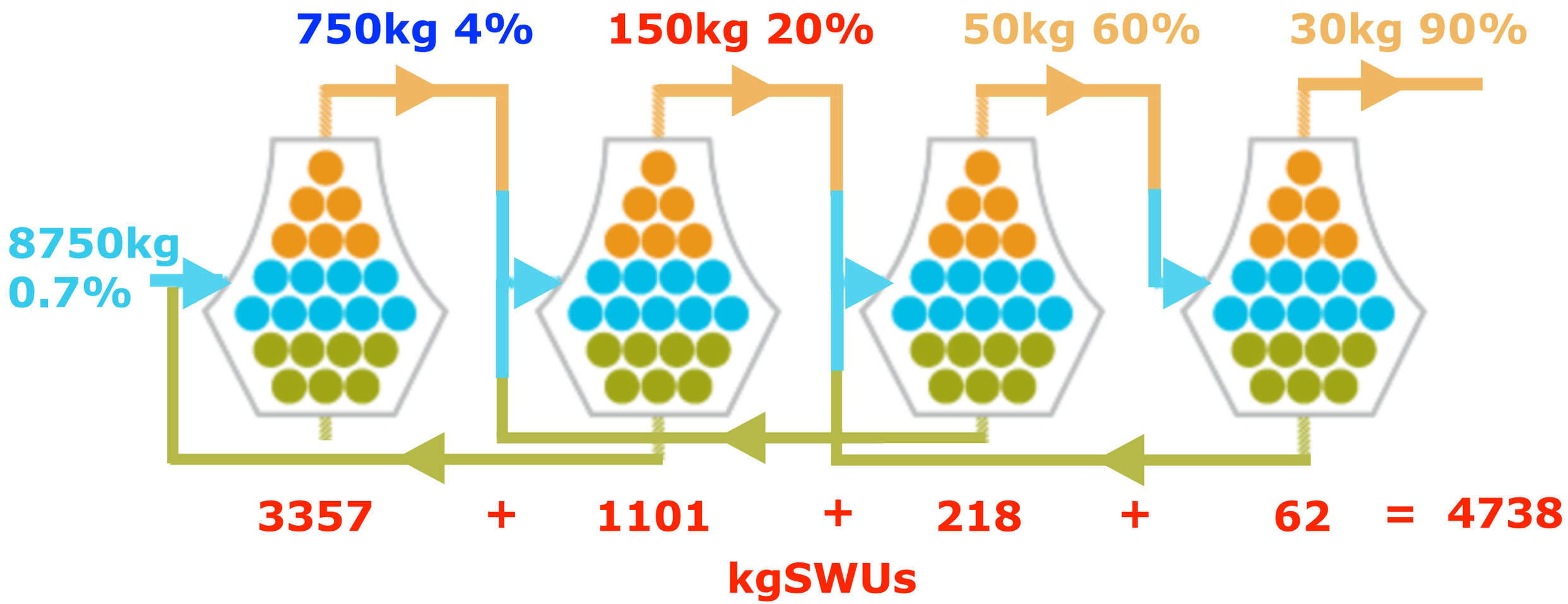
**Need ~$10^5$ IR-1's for one reactor**

# Enrichment Work is Measured in Separative Work Units (kgSWUs)




- **The kgSWU "in" a pile of U equals its mass times the value function, V.**
- **It takes kgSWU to push away from 50:50**
- **A lot of kgSWU in low $^{235}U$ tails – lots of mass & high V**
- **Not much kgSWU to go from 20% to 90% – not much mass, low V**

# To make Weapons-Grade Uranium
# Hook many Cascades in Series/Parallel



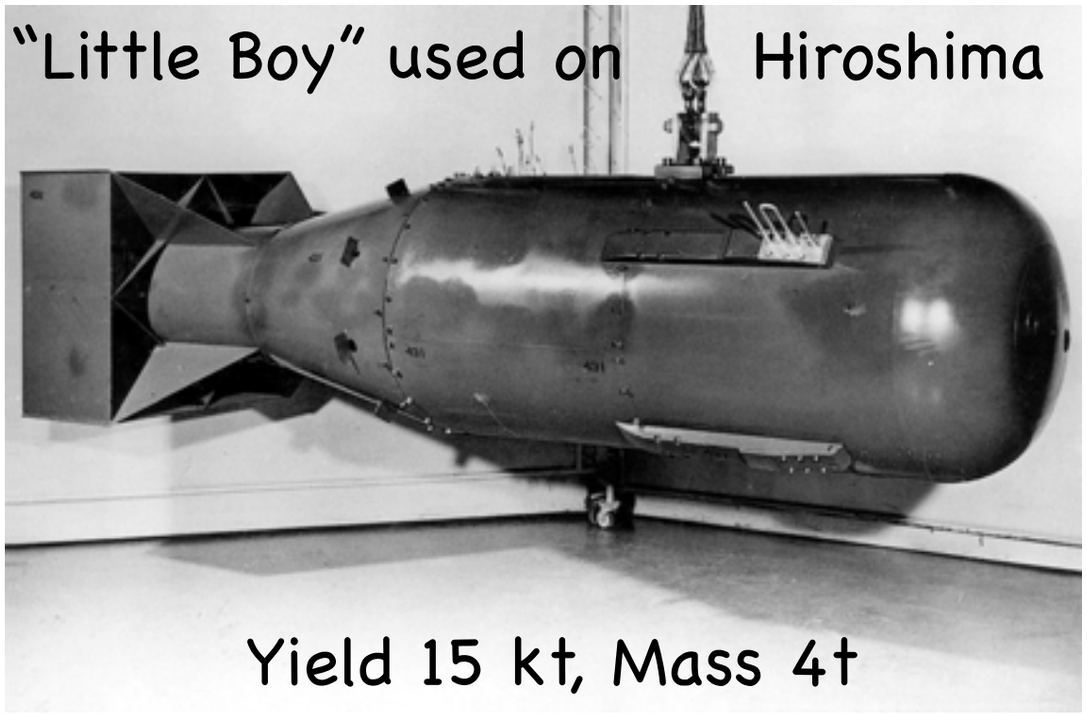

- Starting with 4% (or 20%) enriched U requires 29% (6%) of the kgSWU
- If you start with 4% enriched U, enrichment capability for one reactor = 7 bombs/month

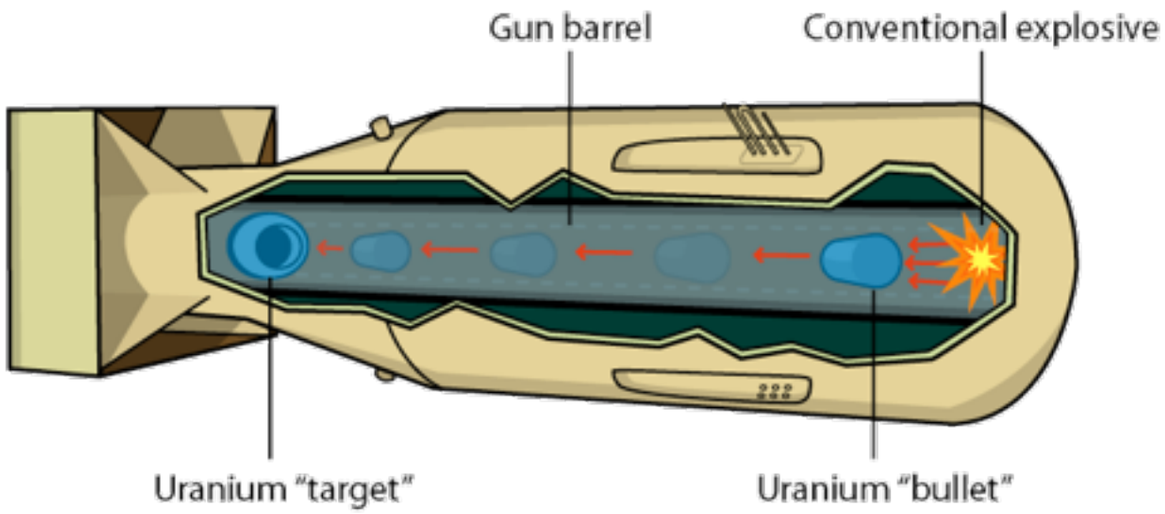
# Iran has Two Declared Uranium Enrichment Sites

- Accommodates 50,000 centrifuges
- 17,000 installed
- 9,000 IR-1's operating ~ 7000 kgSWU/year
- 1000 IR-2m not operating

- Accommodates 3000 centrifuges
- 2700 IR-1's installed
- 700 IR-1's operating

# Uranium-Based Weapons can be Simple




- **Assemble > 1 critical mass quickly**
- **Does not require prior testing**
- **U designs proliferated by China & Pakistan are said to be more compact than Little Boy**
- **Do they need testing? North Korea?**

# Plutonium Path to Weapons Material

- $^{238}U$ in reactor fuel is converted to $^{239}Pu$ by neutrons that drop out of the chain-reaction
- Light water reactors are not efficient for this: H in the water captures many neutrons. Requires ~ 4% enriched U so $^{235}U$ captures more than $^{238}U$.
- Run normally, they also produce much $^{240}Pu$ by another neutron capture. This is less convenient weapons material: it produces heat & neutrons
- Nonetheless it can be used for weapons and needs to be safeguarded

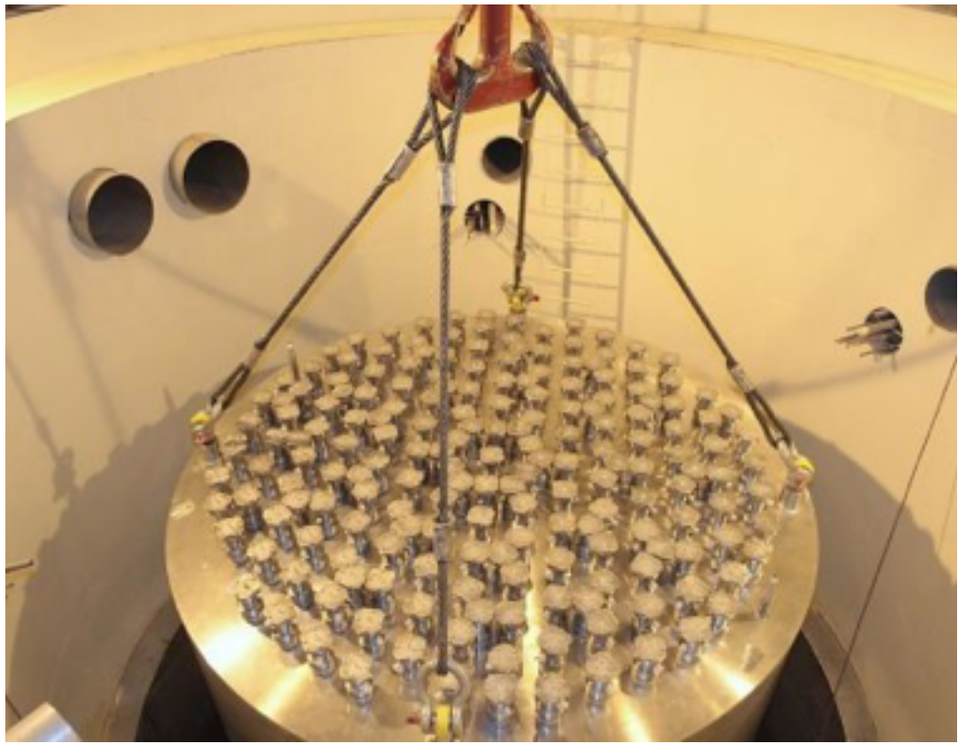
Bushehr Reactor

- Russia has agreed to take back their spent fuel, containing Pu, from Bushehr.
- What happens if/when Iran makes its own fuel for its reactors?

# Plutonium Path to Weapons Material "Research" Reactors

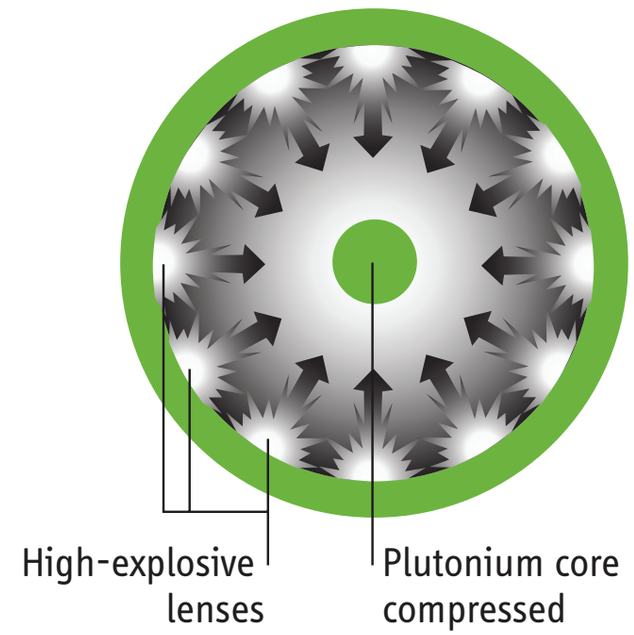
- Heavy water ($D_20$) cooled and graphite moderated reactors capture so few neutrons they can run on natural uranium. So they are very efficient at producing weapons-grade (> 90% $^{239}Pu$) material.
- This is how all countries to date have made Pu for weapons.
- Arak heavy water reactor would have produced > 1 weapon's worth of Pu per year

Arak Calandria



- Arak will be redesigned to produce ~5x less Pu, by burning enriched U, and will export spent fuel abroad every year (Princeton SGS)

# Plutonium Weapons are more Complex




- Compress solid sphere to > 1 critical mass very quickly
  - Burnup > simple assembly, avoids pre-detonation
- Requires μsec timing, so prior testing
- Modern designs are much more compact than little boy
- Collaboration with N. Korea?

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# Breakout

- "**Breakout**" is defined as expelling the inspectors and moving quickly to constructing a weapon.
- "**Breakout time**" is (newly) defined as the time to produce enough material for a single weapon.
- Since 4% (and especially 20%) enriched uranium gives a big head start, for a given breakout time, Iran can have more centrifuges if it has less enriched U in country. (Princeton SGS)
- In fact it is better to minimize U than centrifuges. $UF_6$ is portable, but centrifuges are sitting ducks.

# Sneakout (new word)

- A small, hidden enrichment facility could rapidly produce HEU for a bomb, especially from pre-enriched U.
- A small, hidden reprocessing facility could rapidly produce plutonium for a bomb from spent fuel.
  - Russia has "take-back" policy on spent fuel
- To mitigate these risks, the IAEA needs rapid Anywhere, Anytime, (Anyone) access.
  - Tracking Uranium mines → spent fuel is a powerful new verification capability.
  - There is a problem with the "Anyone" element. Someone has been killing Iranian nuclear scientists.
- Access needed to resolve "Possible Military Dimensions". There is no shame in Iran's activities before 2003.
  - George Bush thought Iraq had nuclear weapons in 2002.
  - Ayatollah Khamenei declared his fatwa in ~2004.

# What has Iran Told the IAEA?

**"As I have said, when we started the [nuclear] work, we were at war, and we wanted to have such an option for the day our enemies wanted to use nuclear weapons. This was [our] state of mind, but things never become serious. …**

**The principle of our doctrine was the use of nuclear [energy] for peaceful purposes, even though we never abandoned [the idea] that if we were some day to face a certain threat, and if it became necessary, then we would have the option of going to the other side [i.e. to develop nuclear weapons]. But we did not have a plan to do this, and we never deviated [from civilian use]…"**

**Akbar Hashemi Rafsanjani, Head of Expediency Council**
**October 26, 2015, Iran's Nuclear Hope online magazine**

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90 days after approval of UNSC resolution 2231 endorsing the JCPOA, assuming Iran provides the IAEA with required information

## Iranian Cooperation with IAEA:

**Iran must provide the IAEA with all information necessary to complete its PMD investigation by October 15.**

ADOPTION DAY

## On Adoption Day:

- **Both Iran and the P5+1 begin taking steps to implement the agreement.**
- **The EU shall adopt regulations terminating nuclear-related sanctions to go into effect on Implementation Day.**
- **The U.S. President shall issue sanctions waivers to take effect on Implementation Day**

## Iranian Actions Necessary Before Implementation and Sanctions Relief:

The following actions must be verified by the IAEA as complete before Implementation Day.

**Iran must disassemble, remove, and store under IAEA seal more than 13,000 excess centrifuges, Including excess advanced centrifuge machines**

**Iran must reduce its stockpile of low-enriched uranium to no more than 300 kg**

**Iran must convert the Fordow enrichment site to a R & D facility**

**Iran must remove and disable the core of the Arak heavy-water reactor**

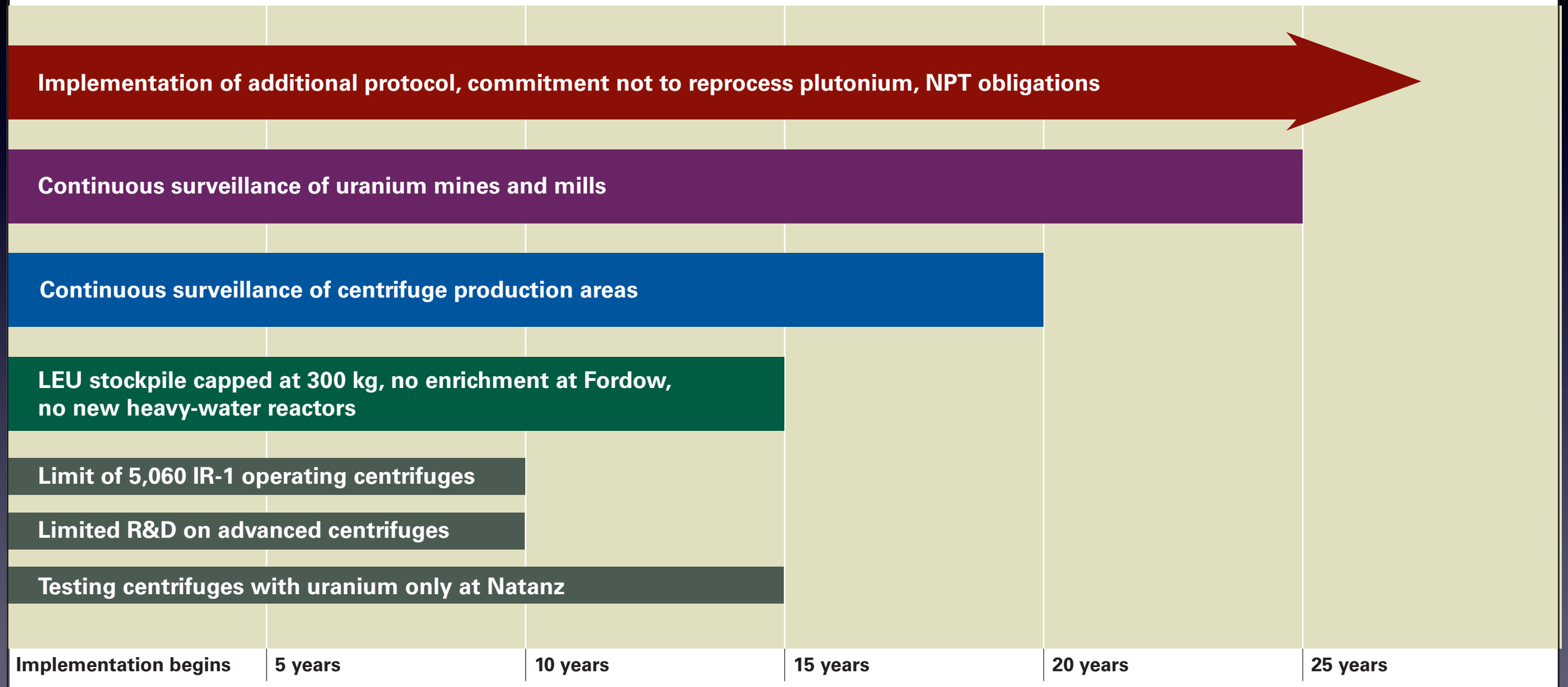
**Iran must allow and make necessary arrangement for additional IAEA access and monitoring**

IMPLEMENTATION DAY

| Before October 15 | October 19 | Adoption Day to Implementaion Day |
|---|---|---|

Arms Control Association

# Key Restrictions Will Last Significantly More than Decade




Arms Control Association

# 29 Scientists' Letter, Aug 8, 2015

- "… an innovative agreement, with much more stringent constraints than any previously negotiated non-proliferation framework."
- "… also provides for innovative approaches to verification"
- "Concerns about clandestine activities in Iran are greatly mitigated by the dispute resolution mechanism built into the agreement."
- "… we find that the deal includes important long-term verification procedures that last until 2040, and others that last indefinitely under the NPT and its Additional Protocol."
- "… gain agreement to implement some of the key innovations included in the JCPOA into existing safeguards"

Dick Garwin, Rob Goldston, Rush Holt, Scott Kemp, Frank von Hippel

# In Just one Tweet

Interim Deal

JCPOA

and 3x less SWU/year

# And How about This?

## JCPOA Annex III – Civil Nuclear Cooperation

1. - **Fusion technology and plasma physics and related infrastructure and facilitating contribution of Iran to the International Thermonuclear Experimental Reactor (ITER) Project and/or similar projects, including relevant IAEA technical cooperation projects**