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REPORT

# Entering Dangerous, Uncharted Waters: Iran's 60 Percent Highly Enriched Uranium

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As soon as mid-to-late April, Iran is expected to reach a new dangerous, destabilizing threshold, having enough highly enriched uranium (HEU) to fashion a nuclear explosive, about 40-42 kilograms (kg) of 60 percent enriched uranium (uranium mass).[1] With this quantity, an enrichment level of 60 percent suffices to create a relatively compact nuclear explosive; further enrichment to 80 or 90 percent is not needed. According to the International Atomic Energy Agency (IAEA), 41.7 kg of 60 percent enriched uranium (uranium mass) is a significant quantity, which the IAEA defines as the "approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive cannot be excluded."[2]

A common fallacy is Iran would require 90 percent HEU, more commonly called weapon-grade uranium, to build nuclear explosives. Although Iran's nuclear weapons designs have focused on 90 percent HEU and likely prefer that enrichment, modifying them for 60 percent HEU would be straightforward and well within Iran's capabilities.[3] Historically, the term highly enriched uranium was developed in the nuclear weapon states to distinguish between enriched uranium able to fuel a practical nuclear weapon versus enriched uranium, labeled low enriched uranium, unable to do so. Their cutoff is at 20 percent enriched uranium. At the least, a device made from 60 percent HEU would be suitable for underground nuclear testing or delivery by a crude delivery system such as an aircraft, shipping container, or truck, sufficient to establish Iran as a nuclear power.

Moreover, Iran could further enrich its stock of 60 percent enriched uranium quickly to weapon-grade uranium, where this threshold quantity would be enough to produce about 25 kilograms, enough for a nuclear weapon and close to the IAEA-defined significant quantity. The delay caused by further enrichment would be measured in days if Iran used a significant part of its enrichment capacity and weeks if Iran operates just two production-scale cascades of advanced centrifuges.

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[1] Uranium mass is used in the report unless otherwise noted.
[2] *IAEA Safeguards Glossary,* International Atomic Energy Agency, https://www.iaea.org/sites/default/files/iaea_safeguards_glossary.pdf.
[3] David Albright with Sarah Burkhard and the Good ISIS Team, *Iran's Perilous Pursuit of Nuclear Weapons* (Washington, DC: Institute for Science and International Security Press, 2021).

Avoiding this uncharted threshold is a priority. To that end, Iran's recent move to chemically convert some of its HEU into an oxide form would suggest positive news, but it is not a remedy and does not prevent other dangerous situations. This new development does not reduce breakout timelines, may disguise preparation to make HEU metal, and creates other dangerous precedents. Moreover, Iran's actions stand in sharp conflict with today's international norms to avoid civilian HEU.

As this report was being finalized for publication, Iran's head of the Atomic Energy Organization of Iran (AEOI) announced that Iran would keep 2.5 kg of its 60 percent enriched uranium stock, referring to a draft nuclear deal that is yet to be finalized.[4] His comment implies the rest of the HEU stock would be eliminated in some manner. The 2.5 kg is likely a part of the HEU stock that has been converted into oxide form and partly used to make target plates for the Tehran Research Reactor (TRR). While such an agreement would reduce the 60 percent stock dramatically, it would legitimize Iran's use of civilian HEU and allow Iran to lock in a valuable precedent for HEU production, conversion, irradiation, and processing later. If true, this concession would represent a significant weakening of the conditions in the Joint Comprehensive Plan of Action (JCPOA). This report will shed light on what this 2.5 kg quantity of 60 percent is, its usefulness in a breakout, and the risks posed by Iran's production and use of HEU.

## Accumulation and Conversion of HEU

We estimated several months ago, first based on the quarterly IAEA Iran report from November 2021, and then again in March 2022, that Iran could accumulate a significant quantity of 60 percent HEU by spring 2022, based on its average daily production of 60 percent HEU up to the date of the IAEA reports.[5] More specifically, based on Iran's daily average production of 0.149 kg 60 percent HEU (uranium mass) from December 2021 through February 2022, and a stock of 33.2 kg as of February 19, it would have taken Iran 46 days, or until April 6, 2022, to accumulate 40 kg of 60 percent HEU (uranium mass).

In early March 2022, Iran converted a small quantity of its stock of 60 percent enriched uranium hexafluoride into an oxide form at an Esfahan facility, for subsequent use as targets in the Tehran Research Reactor to make molybdenum 99 (moly-99), a medical isotope.[6] Earlier, it

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[4] IRNA, "Iran's Atomic Chief Vows 'Nuclear Renaissance,'" Islamic Republic News Agency, April 6, 2022, https://en.irna.ir/news/84707163/Iran-s-atomic-chief-vows-nuclear-renaissance. Eslami did not clarify whether he was referring to uranium mass.

[5] David Albright, Sarah Burkhard, and Andrea Stricker, "Analysis of IAEA Iran Verification and Monitoring Report - November 2021," *Institute for Science and International Security*, November 19, 2021, https://isis-online.org/isis-reports/detail/analysis-of-iaea-iran-verification-and-monitoring-report-november-2021/8; and David Albright, Sarah Burkhard, and Andrea Stricker, "Analysis of IAEA Iran Verification and Monitoring Report - March 2022," *Institute for Science and International Security*, March 4, 2022, https://isis-online.org/isis-reports/detail/analysis-of-iaea-iran-verification-and-monitoring-report-march-2022.

[6] Director General, *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015),* GOV/INF/2022/8, March 16, 2022.

had shipped 23.7 kg of 60 percent HEU hexafluoride to Esfahan from the Natanz enrichment plant. However, Iran's recent conversion of just 2.1 kg of HEU–equaling the amount Iran produces on average in two weeks–would only marginally delay the timeline to accumulate 40 kg to April 21.

Even if Iran converted a second batch of 2.1 kg HEU$F_6$ to $U_3O_8$ in March 2022, this would roughly balance out the 4.5 kg of 60 percent enriched uranium (uranium mass) Iran is expected to have produced in March, based on its average monthly production earlier this year. If so, breakout timelines, which heavily depend on the 60 percent stock, would be roughly the same as at the end of February, absent a change in enrichment capacity.

Some may argue that chemical conversion into an oxide form does lengthen the breakout timeline. It is true it could take longer to convert the oxide compound back to hexafluoride form for enrichment in centrifuges than produce the first quantity of weapon-grade uranium, when breakout timelines are measured in terms of a few weeks. However, it could be reconverted to hexafluoride form for use in producing subsequent quantities of weapon-grade uranium and certainly used in producing the first weapon-grade quantity if the breakout timeline lengthens significantly.

It is also true that breakout timelines would lengthen if Iran converted additional 60 percent HEU from $UF_6$ to $U_3O_8$ and made and irradiated HEU fuel plates faster than it produced new 60 percent enriched uranium. Irradiation in the TRR does make it harder to reuse the HEU. But it is unlikely if any but a tiny quantity of the HEU stock could be irradiated in the TRR. The TRR is a small reactor with a power of only 5 megawatts-thermal and less than optimal neutron fluxes to irradiate the HEU, leaving little space or capacity to use any but small amounts of HEU in targets.

Alternatively, the HEU oxide could be converted into HEU metal for direct use in a nuclear weapon if further enrichment was not desired. In that sense, Iran's transfer of 23.3 kg of 60 percent enriched uranium hexafluoride from the Natanz enrichment site to Esfahan could be interpreted as preparation for using the bulk of this material in a breakout to a nuclear explosive using 60 percent enriched uranium.

Because conversion from HEU oxide to HEU hexafluoride or HEU metal is so straightforward, converting HEU hexafluoride into an oxide form is usually not seen as proliferation resistant or a substitute to a ban on production of HEU combined with the blending down or export of all national stocks of HEU.

## Target Production

The conversion of 60 percent enriched uranium to targets involves several steps with two critical stages, one, the production of $U_3O_8$ from highly enriched $UF_6$, and two, the production of the target plate, which likely involves the pressing together of the $U_3O_8$ powder with aluminum powder.

Iran reached the first stage of converting 2.1 kg 60 percent $UF_6$, or $HEUF_6$, into 1.8 kg $HEU_3O_8$ between March 7 and March 9, 2022.[7] (Eslami is likely referring to this HEU, despite the numbers not matching exactly.) These amounts are given in uranium mass and indicate a loss and scrap rate of 300 grams of 60 percent uranium, or 14 percent.[8]

On March 11, Iran began stage two, making the target plates. Each plate contains about 5.8 grams of HEU mass. By March 15, Iran had produced a total of 88 targets, containing 515.7 grams of 60 percent uranium (5.86 grams per target and 3.52 grams of uranium 235 per target). If Iran continued producing targets at this rate, Iran may have used all or nearly all of the 1.8 kg uranium in the form of $HEU_3O_8$ by the end of March.

On March 15, Iran told the IAEA that it had inserted 32 HEU targets into the TRR for irradiation to make moly-99, containing 186.7 grams of HEU. The irradiation cycle for moly-99 production is relatively short, typically about one week, although the exact length is not known for the TRR, which has a lower thermal neutron flux than other reactors making moly-99. Nonetheless, assuming a seven day irradiation cycle, and a steady state of 32 targets per week for 21 weeks per year,[9] the total annual need for HEU would be about 4 kg. This value could be increased somewhat, but is just as likely to be lower, given the reactor's age and relatively low power. But this calculation indicates that the maximum amount of HEU usable in targets to make moly-99 is very low, in particular compared to Iran's recent production levels of HEU.

Iran also announced in March that it intends to separate the moly-99 from the irradiated HEU and other fission products at the hot cells at the Molybdenum, Iodine, and Xenon Radioisotope Production (MIX) facility. Such processing would need to occur soon after the targets are irradiated since moly-99 has a half-life of only 66 hours, less than three days, meaning that delays result in rapid losses of moly-99 through radioactive decay. Moly-99 thus cannot be stockpiled in the irradiated target. Typically, moly-99 production and use in medicine is tightly scheduled and highly time dependent. Because the HEU target is only lightly irradiated, the recovered HEU remains near its original enrichment level. So, moly-99 production is not a method of eliminating HEU.

It is possible that Iran has converted additional 60 percent enriched uranium to $U_3O_8$, utilizing more of the 23.3 kg of HEU transferred earlier to Esfahan from Natanz. With the small amount usable in targets, significant conversion would be unlikely for moly-99 production. Moreover, the initial conversion suffered relatively high losses, 300 grams. While this amount may appear

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[7] *Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015),* GOV/INF/2022/8, March 16, 2022.

[8] If the amounts given included the mass of the other elements in the chemical compounds, fluorine and oxygen, respectively, the amounts would translate to 1.416 kg uranium mass and 1.525 kg uranium mass. Since an increase in uranium mass is not plausible, the unit appears to be uranium mass only.

[9] "Research Reactor Details – TRR", International Atomic Energy Agency, http://www-naweb.iaea.org/napc/physics/research_reactors/database/RR%20Data%20Base/datasets/report/Iran,%20Islamic%20Republic%20of%20%20Research%20Reactor%20Details%20-%20TRR.htm.

small, it is relatively large compared to Iran's production of 60 percent enriched uranium, where daily average production was at just below 150 grams in the early months of 2022.[10] Despite the losses, which could be reduced via practice, conversion could continue as a step in eventually going from HEU hexafluoride to HEU metal.

## Violations of International Norms

Often lost in this discussion is that sixty percent enriched uranium is not needed to produce moly-99, since 20 percent enrichment is today's universally accepted upper bound enrichment level for moly targets. All of the major commercial producers of moly-99 have agreed to this norm.[11]

Iran's recent actions are thus seen as provocative, especially since the rest of the world has spent decades converting to the use of low enriched uranium targets to make moly-99, some even use natural uranium.[12] One of the last of the major holdouts on conversion, the 100 megawatt-thermal Belgium BR reactor, a reactor twenty times larger than the Tehran Research Reactor, started its conversion to the use of LEU targets in 2020 and is expected to finish it in 2022.[13] The entire purpose of this global, multi-decade effort is to reduce the amount of HEU in the civilian fuel cycle, thereby reducing the proliferation risks, including to terrorists, posed by HEU. Iran appears insensitive to this effort, even though it could use low enriched uranium, even natural uranium, to make moly-99, increasing doubts that its true purpose is purely civilian.

Given Iran's poor non-proliferation credentials, one must ask whether Iran will try to use moly-99 production as a justification to produce 90 percent HEU. Like in nuclear weapons, 60 percent enriched uranium is sufficient for moly-99 production, but 90 percent material is better. Afterall, moly-99 is a fission product of U-235, and the more available the uranium 235, the more moly-99 can accumulate in each target.

Not only is this a dangerous idea, its logic is contradicted by the accomplishments of the multi-decade, multi-lateral efforts to design and produce reliable LEU targets. These targets have an increased density of uranium, allowing for a greater density of uranium 235 as well, compensating for the lower enrichment level. After several decades of work, the world's reactor programs have lowered the enrichment level in targets to below 20 percent. Iran's actions stand in sharp contrast to that worldwide effort and should be fiercely resisted.

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[10] "Analysis of IAEA Iran Verification and Monitoring Report - March 2022."

[11] "Report on Radioisotope Production by Working Group 3, Chaired by the Netherlands," The 3rd International Symposium on HEU Minimization, 5-7 June 2018, Oslo, Norway, https://www.stimson.org/wp-content/uploads/2021/01/WG3-OSLO2.pdf. For additional background on the amounts of HEU in civilian use historically, see Institute for Science and International Security, *Civilian HEU Watch* at https://isis-online.org/uploads/isis-reports/documents/Civil_Stocks_of_HEU_Worldwide_October_7_2015_Final.pdf.

[12] "Report on Radioisotope Production by Working Group 3, Chaired by the Netherlands."

[13] World Nuclear News, "Belgium starts producing Mo-99 using LEU," May 4, 2020, https://www.world-nuclear-news.org/Articles/Belgium-starts-producing-Mo-99-using-LEU.

## Conclusion

Absent IAEA assurance that Iran's nuclear program is peaceful, Iran's production and use of HEU should be seen as directly or via further enrichment building a stock of material intended for use in nuclear weapons, a way to be more prepared to build nuclear weapons in the event the leadership gives the order.

It is hard to fathom Iran's internal thinking behind its recent, provocative HEU conversion. Is it to give a misleading impression of limiting its stock of 60 percent enriched uranium hexafluoride below a key threshold? Or is it a sly attempt to create a precedent or excuse to produce it in the future in a post-nuclear limitation environment, or even keep a portion of its 60 percent stock in case of a nuclear deal? AEOI-head Eslami's proud declaration of keeping some of the HEU under a deal would suggest Iran has achieved the latter to the detriment of the West.

Although conversion followed by irradiation reduces Iran's usable HEU stock marginally in a breakout, this is not a viable pathway and creates an unnecessary and dangerous precedent for the use of HEU in its civil nuclear program. This precedent could justify Iran's further production of HEU in the absence of a deal, in the event of a new nuclear deal following the sunset on enrichment levels, or after a future deal's breakdown. A sounder position is to insist that Iran stop producing HEU permanently and ship out or blend down to low enriched uranium its whole HEU stock, whatever its form.