Cutting Through the Fog on ‘Possible Military Dimensions’ to Iran’s Nuclear Programme: Signatures in the production of Highly Enriched Uranium (HEU) metal parts for weapons

by Robert Kelley

There are many signatures associated with the conversion of Highly Enriched Uranium (HEU) hexafluoride (UF_6) to metal parts for use in fabricating a nuclear weapon. This assessment considers those steps and the signatures they create for an inspection team. We are not asserting in any way that Iran has, or is planning to produce HEU metal parts, only showing what vulnerabilities would be created if Iran did so. This is in the context of understanding the widely misunderstood requirement in the Joint Comprehensive Plan of Action (JCPOA)[1] that Iran could delay inspections for up to 24 days and consequently could hide, scrub, or sanitize all traces of nuclear activity.

The processes we are about to describe apply not only to HEU but also to lower grades of uranium including natural and depleted uranium. Lower quality (Natural or Depleted Uranium) will be used extensively for process development and proof tests as well as for some non-fissile structural components. We will return to this later.

The starting material for a uranium metal parts programme is uranium hexafluoride gas (UF_6). This gas would be reduced to UF_4 (uranium tetrafluoride), so-called Green Salt.

Green Salt would be mixed with magnesium (possibly calcium) metal chips in a blender and compacted in a bomb reduction vessel. Bomb reaction vessels are very strong steel containers that hold the charge of UF_4 and magnesium chips. The word ‘bomb’ is common chemical engineering jargon and not the military sense of a bomb. When heated there is a violent exothermic reaction and uranium metal liquid sinks to the bottom of the chamber to solidify.

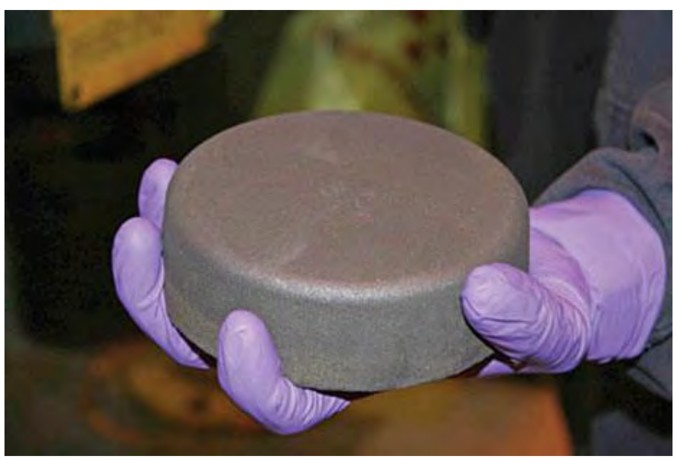
Typical bomb reduction vessels

[1] http://www.un.org/en/ga/search/view_doc.asp?symbol=S/RES/2231(2015).0, paragraph 78, page 32.

The output of such a vessel from this process is a rough metal *dingot* (*direct reduction ingot*) of uranium metal, a contaminated bomb reduction vessel, magnesium fluoride waste containing significant traces of uranium and contaminated crucibles. Waste from this step will be sent to scrap recovery if HEU is being processed due to the high value of the HEU.

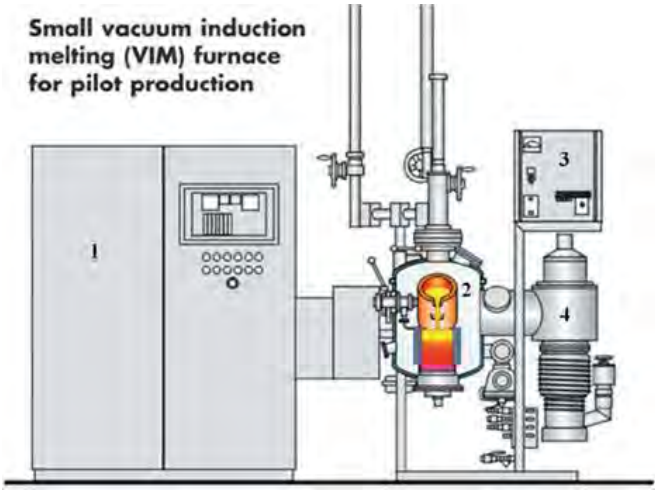
The bomb reduction and casting processes create lots of scrap that has to be dissolved and recycled back to pure metal

The *dingot* will be sent to chemical analysis to ensure that it meets chemical specifications for impurities. If it does not, it will be sent for chemical purification which creates a lot more waste and recycled material. That includes a second trip through the bomb reduction vessel. Leftovers from chemical analysis will contaminate instruments and create a new waste stream.



Clean metal ingot ready for casting into weapons shape

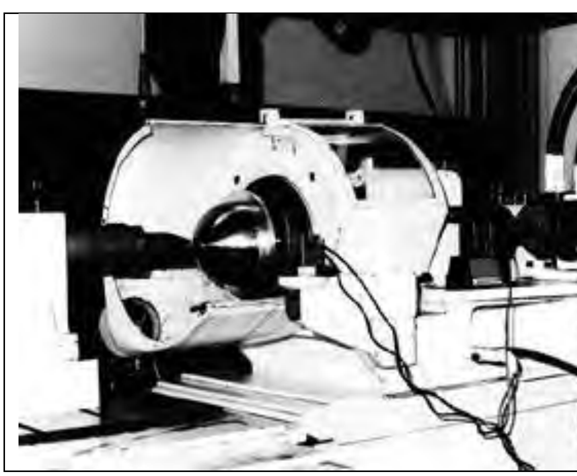
When several acceptable *dingots* are acquired they will be melted together to form feed material for a casting furnace. Melting, and later casting, will be done under high vacuum conditions because uranium reacts strongly with oxygen and even burns under the right conditions. The large furnaces will have extensive vacuum systems integrated into them and will have a modern induction furnace or vacuum arc remelting furnace for the melt itself. It all can be contained in a glove box to prevent contamination of the room and equipment. Although uranium is not particularly hazardous to health there is a presumption that minimizing contamination for inspectors to find later is a priority. Of course the contaminated glove boxes and the equipment inside become a greater problem for decontamination, removal and disposal.



The melting process will result in a waste stream of crucibles, vacuum pump oils and equipment, moulds and tooling. This will be mostly particulates and some will be very fine because the thin films of uranium on the furnace interior will likely burn and flake off. The very fine particles of burnt uranium will become a contaminant problem.

At this stage acceptable metal parts are in the form of rough castings ready for machining. Samples will be taken again from the sprue, the thin cylinder of uranium that projects above the casting mould. Naturally, the casting crucible will inject more HEU into the mould than necessary so that the weapons part in the mould will be complete. There will be a lot of waste in the crucible and the pour funnel to be recycled. The cast part will be radiographed and subjected to density measurements that verify its quality.

Next comes machining. The uranium parts will be formed on high precision lathes and mills as necessary to produce the spherical shape and other necessary features.



This is a plutonium part being machined in a lathe. The process for uranium would look the same. Uranium might or might not be done in a glove box depending on whether the operator is trying to hide uranium particles from inspectors

A significant amount of the metal, possibly 20% or more will be turned to small chips of metal as they are machined off. The chips will burn in air in many cases and will be contaminated with machining fluid and cutting tool bits. These valuable chips will be sent for wet chemical processing, recycle and purification due to their very high value.

Uranium machining chips being cleaned for recycle

Following machining, the finished parts will be inspected for quality. Those that pass the quality tests will be ready for plating to prevent corrosion. Then, they are finally ready to become weapons parts. Parts that fail the examination must be recycled completely.

Along the way there were hundreds of grams of extremely valuable scrap produced that needs to be recycled, much of it through wet chemistry in criticality-safe solutions. There will be particulates, acids, oils and unrecoverable waste. Many samples will be taken for mass spectrometry, atomic absorption spectroscopy, x-ray diffraction, fluorescence, density and optical metallography. All these processes produce scrap and waste that needs to be recycled or collected. As the scope of the operation grows beyond the first one weapon, the number of people performing these tasks and their work stations also grow. People will become contaminated, at least to the point of wanting clean clothes. There will be a laundry for the clothing and showers for the staff. The waste water will run into sewers, or better yet into septic tanks and a leach field. This will be ripe sampling territory under an inspection regime. Inspectors dragging samples from sewage sludge!

Neglected in many analyses of this necessary work to produce uranium metal parts for weapons is process development. A state that wants to produce weapons metal parts does not begin its development programme using its precious HEU. The state will begin possibly years in advance to do trial runs of all the processes above: reduction, melting, alloying, casting, machining, scrap recycle, chemical and metallurgical characterization. These trial process development steps will use natural or depleted uranium as a stand-in. There likely will be dozens of experiments and variations on surrogate material before the state will certify the ability to produce weapons quality parts. There will be many more experiments on surrogates than on the real thing because that is the only way to achieve quality.

It becomes obvious to engineers, industrial, chemical, nuclear, that this is no small enterprise to be conducted in the back room after enrichment is done. It is a significant undertaking. There is a precedent that is well known to non-proliferation experts: Iraq. Iraq considered all of the issues above and realized that if it was going to have even a small HEU metal programme for weapons, they needed a facility. The facility Iraq built at Al Atheer was about 5000 m^2 and incorporated space and equipment for the tasks we have described. It was properly designed to have two parallel facilities, one for handling natural uranium for process development and a separate, parallel and more complex one for HEU. The main differences between the two were that natural uranium is cheap and there is no need to recycle scrap as with HEU; and natural uranium has no criticality issues and can be handled in large batches. This Casting Building as it became known was inspected in 1991 by US and UK experts in nuclear weapons work and immediately identified as a weapons part production facility. It had extensive ventilation and filtration systems for the glove box and hood lines, pump exhausts and a separate system for room air purification. There were sewers and leach fields and waste storage tanks. This facility was nearly complete, but had not reached the point of introducing nuclear materials so IAEA sampling was not an important issue. If it had been handling nuclear material, the tons of equipment and auxiliary equipment including waste lines would have provided an unlimited rich environment for wipe samples and other means.

Conclusion

Newcomers to the nuclear weapons world are known to write off uranium metal part production as a tiny and insignificant aspect of a nuclear weapons programme. Hence they can argue that a proliferating state could easily remove and sanitize a facility designed to produce high quality uranium parts for a nuclear weapons programme. They will assert it could be done in less than 24 days, the JCPOA worst case benchmark. Experienced personnel will strongly disagree. There are many stages of work from conversion of uranium hexafluoride to finished uranium metal parts. There are numerous recycle loops where extremely valuable HEU will be recovered and converted at some serious cost to pure uranium feed material again. Chemical and metallurgical laboratories are essential to procuring acceptable parts. Even the shower room and laundry will contribute to waste streams and traces of uranium to be found in a serious inspection.

Policy-makers and the media need to stop relying on amateurs for information. So-called pundits who claim that the metal-making stage is easily concealed and therefore easy to hide are completely wrong. These assertions impact the credibility of the whole debate.