Securing the European Supply of 19.75% Enriched Uranium Fuel

PROPOSED OPTIONS

Euratom Supply Agency (ESA)
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REPORT OF THE WORKING GROUP ON EUROPEAN PRODUCTION OF 19.75% LEU 3RD MANDATE – May 2022

1. Introduction

Research reactors are vital to a number of scientific disciplines, basic research, materials research, nuclear physics and life sciences. In addition, they are essential for nuclear safety in the European Union by testing existing and future materials under irradiation, for example for the production of homogenously doped silicon and urgently needed radioisotopes for industry and medicine. Thus, neutrons produced in research reactors not only enable scientific progress, but are also crucial to the development of technology applications, production and qualification of materials and nuclear medicine. Today, the European Union with its high-performance research reactors (EU-HPRR) and diversity in nuclear technologies is leading in science with neutrons and medical radioisotope production.

Traditionally, fuels for the European Union research reactors and radioisotope production targets have been manufactured using highly enriched uranium (HEU), supplied mainly from the USA and Russia.

Over time the supply and use of HEU have become subject to additional political and administrative constraints, making the future supplies of HEU uncertain. For example, a ban on the export of HEU for the exclusive purpose of production of medical radioisotopes is in force in the USA since the end of 2021. In addition, due to the current geopolitical developments, HEU supplies from Russia become increasingly uncertain.

In order to reduce the risk of nuclear proliferation, EU Member States are strongly committed to the principle of HEU minimization with the objective of converting research reactors and radioisotope production targets to high-assay low-enriched (19.75%) uranium (HALEU). In line with this political commitment, existing European Union research reactors are actively working to achieve this conversion as soon as technically and economically feasible. Several European Union research reactors and radioisotope production facilities have already made the transition to HALEU successfully, while others have active conversion projects. HALEU is currently exclusively supplied from the USA and Russia.

Next to its use in research reactors and for the production of radioisotopes, HALEU is also gaining attention for the development of fuel systems for advanced reactors, such as SMRs and GenIV-type reactor systems or nuclear-powered space exploration. With higher enrichment, longer fuel cycles become possible and fast reactor systems are more readily deployable. This report however will not take this potential demand into account.

HALEU supplied from the USA is made by the down-blending of existing HEU stockpiles, and the United States (US) Administration anticipates its availability for research reactors until around 2035-2040. This dependency on USA and Russia creates a critical risk to the security of HALEU supply for the needs of the European Union. In order to ensure the future operation of research reactors and radioisotope production, the long-term availability and accessibility of metallic HALEU is a key issue. No commercial facilities for HALEU are currently in operation in the EU, or in the US[1].

Maintaining sovereign know-how and rebuilding some strategic capabilities in the production of HALEU metal is essential for the European Union for the decades to come, given the scale of the associated challenges in the geostrategic, climatic and resource management fields. In particular, at a time when the European Union is seeking to guarantee its strategic autonomy in critical sectors, these capabilities will contribute to European Union secured supply chains for medical radioisotopes.

Therefore, the European Union must examine alternatives to ensure the future availability of such HALEU for its needs. Without any new initiative, there is a risk for the security of supply of this critically important material after 2035.

1 See 4.1 for overview of initiatives to develop HALEU production capacity in the US and UK

2. Working Group objectives

2.1. Mandates 2013 and 2018

By decision of the Advisory Committee of the Euratom Supply Agency (ESA), a Working Group to evaluate ways to secure the European supply of 19.75% enriched Uranium fuel was set up in May 2012. The report of that working group was endorsed in 2013[2] .

In view of the changing landscape of research reactors in the Europe Union, the Advisory Committee re-instated the working group in April 2018. The revised report[3] was endorsed and approved by the Advisory Committee at its session of 21 March 2019.

Since then, the Strategic Agenda for Medical Ionising Radiation Applications (SAMIRA)[4] has been set up. The action plan contributes to the Commission's flagship initiative 'Europe's Beating Cancer Plan' with new actions on the supply of medical radioisotopes, quality and safety, and research and innovation in medical applications of nuclear and radiation technology. It emphasises the need for the European Union strategic autonomy in the supply of medical isotopes, the large majority of which is produced by research reactors. This initiated a 3rd mandate of the working group, the report of which is delivered hereby.

2.2. Third mandate (2021)

The objective of the Working Group under the third mandate is to identify one or several viable schemes for a sustainable European Union supply of metallic HALEU, thereby maintaining sovereign know-how and rebuilding some strategic capabilities in the production of HALEU metal, with involvement of European industrialists and customers using the material. This includes the exploration of the necessary conditions, including European Union public and private sector participations and specific industrial and commercial options, and to facilitate the preparation of the construction, in the European Union, of a HALEU metal production capacity responding to the EU needs for the research reactors fuel and medical radioisotopes production.

3. European Union HALEU needs and opportunities

The supply of metallic HEU involves specific bilateral intergovernmental agreements and commercial contracts concerted and co-signed by ESA. Whereas the supply of HALEU is only requesting commercial contracts concerted and co-signed by ESA. Moreover, international and national transports of HALEU are less constrained.

3.1. European Union needs

The landscape of European Research Reactors for basic research, materials research, nuclear physics and life sciences has evolved since the 2019 report. All these needs, including the strategic need for medical radioisotopes, as stated in the action plan of SAMIRA, are consolidated in the table below.

The future needs for fuel and target HALEU have been re-evaluated, once again within a maximal and minimum scenario. Furthermore, a minimal forecast for the period 2035 – 2050 has been estimated. The latter has been done under the following boundary conditions:

- All European Union research reactors are considered to be converted to HALEU in 2035; targets are already converted.
- European Union research reactors currently supplied by non-European suppliers (in Czech Republic, Hungary, Poland) are put to zero demand in the minimum scenario for 2035.
- The minimum scenario is based on conservative

2 http://ec.europa.eu/euratom/docs/ESA-MEP-rapport.pdf
3 https://euratom-supply.ec.europa.eu/document/download/12807835-097f-4f85-806e-f155722ffedc_en?filename=ESA_HALEU_report_2019.pdf
4 https://energy.ec.europa.eu/topics/nuclear-energy/medical-uses-radiation_en#samira-action-plan

assumptions concerning operation of the different research reactors. Therefore, it can be considered as a safe scenario.

- Projections for 20 years operation between 2035 – 2055 assume no premature shut down of RJH, FRM II, HFR/PALLAS[5] and stable need for targets.

Based on the mandate by the ESA Advisory Committee, the working group has not investigated in this report the consequences from and the synergy with the growing interest and activities to HALEU production for advanced power reactors. It should be however noted that the EU research reactors needs for HALEU will be competing for the material with small modular and advanced reactors (SMR) if that demand increases significantly. This could be an additional risk factor in the medium-term, until the worldwide production capacity adjusts to the market needs.

Table 1: Estimated European HALEU needs on an annual basis

Country	Research Reactor	Power (MW)	Annual Demand HALEU 2030 (kg/y) 2019 Report	Annual Demand HALEU 2035 Maximum Scenario (kg/y)	Annual Demand HALEU 2035 Minimum Scenario (kg/y)
Austria	TRIGA Mark II	0.25	1476	1256	676
Belgium	BR2	60			
Czechia	LVR15	10			
France	JHR	100			
	RHF	58			
Germany	FRM II	20			
Greece	DEMOCRITOS	5			
Hungary	VVR M2	10			
Italy	TRIGA	1			
Netherlands	HOR Delft	2.3			
	HFR	50			
	PALLAS	25 - 30			
Poland	MARIA	30			
Romania	PIETESTI	14			
Targets	^{99}Mo/^{99m}Tc				
Total				***1256 kg/y***	***˜700 kg/y***

5 It is considered that either HFR (Petten) is substituted by the new isotope production reactor PALLAS or a refurbished HFR continues to produce urgently needed medical radioisotopes.

3.2. International HALEU needs for research reactors and medical radioisotopes potentially covered by European Union actors

Traditionally the European Union fuel and target manufacturer provides fuel assemblies and targets to research reactors beyond Europe. An estimation of these additionally needs may be an important input for assessing realistic scenarios for a future European HALEU production. Again, this forecast has been done under certain considerations:

- Again, it is assumed all research reactors are converted to HALEU.
- Conservatively it is assumed that all North, South American and South Korean research reactors are supplied by the US.
- Today and in the perspective towards 2035, the Pacific research reactors OPAL and SAFARI are urgently needed to feed the worldwide needs in medical radioisotopes. However, in a longer perspective it cannot be excluded that SAFARI will be shut down, with or without replacement[6].

In total 120 kg/y for research reactors fuel delivered to the Asian and Pacific regions from a European Union supplier beyond 2035 is a minimum assumption with a considerable probability to be higher.

Table 2: International HALEU needs potentially provided by Europe

Country	Research Reactor	Power (MW)	Annual Demand HALEU 2035 Maximum Scenario (kg/y)	Annual Demand HALEU 2035 Minimum Scenario (kg/y)
Australia	OPAL	20	255	120
South Africa	SAFARI	20		
Total			***255 kg/y***	***120 kg/y***

4. HALEU production forecast

4.1. Current plans for HALEU production in the Western world

The U.S. Department of Energy is committed to support new infrastructures for HALEU production to produce several tens of metric tons before 2030 for the purpose of fueling advanced power reactors. A Request for Information[7] has been issued mid-December 2021 with the aim to support "the availability of HALEU for civilian domestic research, development, demonstration, and commercial use".

While the responses have yet to be made public, recommendations and expert perspectives delivered to the Department of Energy highlighted two challenges: availability of deconversion technology, and HALEU demand certainty. Firm and meaningful HALEU quantity commitments seem to be the single most important factor enabling success.

HALEU demand in the US seems to be for UF6, uranium oxides, and uranium metal for use in advanced reactors, research reactors and targets for medical radioisotopes[8] . Enrichments between 10 % and 19.75 % are envisaged.

It has to be acknowledged that any forecast on the current US stockpile evolution and on the build-up of US HALEU production capacities is subject to large uncertainties and relies on sovereign US decisions. Therefore, this does not provide a robust base for a European Union strategy.

7 https://www.federalregister.gov/documents/2021/12/14/2021-26984/request-for-information-rfi-regarding-planning-for-establishment-of-a-program-to-support-the

6 https://www.world-nuclear-news.org/Articles/South-Africa-seeks-proposals-for-new-research-reac

8 Request for Information (RFI) Regarding Planning for Establishment of a Program To Support the Availability of High-Assay Low-Enriched Uranium (HALEU) for Civilian Domestic Research, Development, Demonstration, and Commercial Use, issued by DOE on 14-12-2021

4.2. *Opportunities for HALEU production in the European Union*

Based on the presented evaluation it can be safely/with high confidence stated that

- by 2035, European Union strategic need will be **700 kg/y**.
- If Hungary, Czech Republic and Poland are no longer supplied by Russia, the European strategic need will increase to **1000 kg/y**.

Therefore, the market for a European Union HALEU production for research reactors serving basic research, materials research, nuclear physics and life sciences beyond 2035 has the following perspectives:

- High confidence : Europe + Opal = **800 kg/y**
- Relevant market opportunities : Europe + OPAL + others = **1200 kg/y**

The European nuclear fuel cycle industry– notably Urenco and ORANO - is world leading in enrichment technology for civil uses and enrichment up to 6% (and up to 10% by 2025). This same technology can be used to produce HALEU (19.75%) without major technical challenges. For reasons of safety (criticality) and security this should be done in a separate and dedicated facility. The final product would be UF6, which then has to be chemically converted to metallic U either on the same site or on a different site[9].

Conversion to uranium metal on an industrial scale has been suspended in Western Europe more than 10 years ago. Yet the industrial knowledge is still present, but risks to vanish in the near future.

Assuming a maximum price of 20 000 € per kg of HALEU, which may still be compatible with funding which is typically available to research reactors, and annual quantities as summarized above, both companies clearly state not to be able to finance the necessary investment and to maintain production within a commercially viable scenario. It is estimated that a guaranteed demand of 3 to 8 t/year is necessary for a European Union HALEU production facility to be commercially viable.

9 For reasons of industrial optimization and minimization of transports, it might be relevant to have enrichment and conversion to U metal within one and the same site, but this depends on the overall context that prevails.

5. Conclusions

5.1. Options for the European Union

In view of the fact that no purely commercial production of HALEU metal in the European Union is in sight for the estimated quantities, the following options can be considered:

Option 1

The European Union relies on timely delivery by the US and Russia.

This option would put the security of supply at risk as from 2030, with increasingly less certainty, due to the current geopolitical circumstances and to the growing uncertainties on the US delivery capacities beyond that date. It does not guarantee the European Union strategic autonomy and likely entails relying on one supplier.

Option 2

A rolling reserve for 10 years of needs is maintained.

ESA would guarantee the permanent availability of 10 years requirements HALEU as stockpile. This would provide an adequate level of security of supply assuming that appropriate mitigation measures are taken in due time whenever the context makes it necessary. This option provides valuable flexibility in the mid-term. However, to mitigate long-term hazards, it is critical to sustain competencies and capacities on relevant technologies.

Option 3

A European Union production capability is built.

This would address both objectives of the strategic autonomy and the security of supply. It would require a long-term vision from EU Member States concerned and commitments from all stakeholders, such as guaranteed purchase commitments of the research reactors and medical industry, public funding, state credits and industry engagement.

Once the decision is taken, installing a facility in the European Union would require 6 to 7 years for designing, engineering, licensing, construction and commissioning, and the plant would be operate for decades.

The three options above offer different level of cost/benefit balance, which deserve comments and further discussion. Option 1 relies on informal information obtained from the U.S. Department of Energy through technical exchanges. This raises two critical questions. The first critical question is related to the deadline forecast robustness; the status of the US stockpile and the associated rate of use are outside of the control of the European Union, which means that a strategy relying on this forecast has itself no robustness. The second point concerns the priority in the use of the remaining material; it is sound to consider that, the closer we are to the deadline, the higher the priority given by the US to domestic customers will be, in particular in view of the upcoming need for the development of advanced reactors. As referred in Chapter 4.1, there is a general trend towards a need for new HALEU production capacities triggered by innovative power reactor development. If this is realised, the perspective for HALEU supply needs will be deeply modified.

5.2 SWOT analysis

Option	1 – The European Union relies on timely delivery by the US and Russia	2 – A rolling reserve for 10 years of needs is maintained	3 – A European Union production capability is built
Strengths	No need for action or investment.	Moderate security of supply. Reduced need for dedicated infrastructure investment for storage facility only. Moderate investment.	EU sovereignty and strategic autonomy. Optimal security of supply, fully in EU control.
Weaknesses	Permanent political and commercial dependency	In view of the current geopolitical developments even short-term availability of HALEU on the market is at risk. It does not provide a solution in case of a long-lasting deadlock in the international market. Retains dependence on third countries.	Requires integrating the complex setup of actions, commitments and/or financing at the relevant EU, Member States, industry and end users.
Opportunities		Can be considered as a realistic first step towards the development of an European Union capacity as of option #3 in a graded approach.	Maintenance and development of critical competencies and capacities in relevant technologies. Industrial knowhow and production in the European Union.
Threats	High risk to security of supply depending on geopolitical context and foreign suppliers decisions on their own market and political priorities. Danger of monopole or cartel prices. Loss of critical competencies and capacities in relevant technologies. Dependency on security requirements for the export of LEU materials from the supplier countries.	The building of the stockpile (high impact) or rolling (low impact) supply could be interrupted by foreign suppliers decisions based on their own market and political priorities. Loss of critical competencies and capacities in relevant technologies if not maintained. Dependency on security requirements for the export of LEU materials from the supplier countries.	The industry does not receive the EU political signal on time to make their investment in the EU relevant. Delays in decision-making and/or implementation may lead to the EU facility production not available by the required time. Foreign suppliers may affect negatively the market with dumping price policies, pushing some parties toward opportunistic behaviour and leaving the European Union investment process without expected return on investment.
Enablers	Not required. Business as usual. Not under EU control.	Requires a legal framework and financing to enable ESA acting. Requires a storage location/facility.	Requires timely vision, commitment and possibly financing on the EU and Member States levels.

5.3. Recommendations

Option 1 is clearly the least preferred, as it would not address the security of supply risks.

Only Option 3 assures the EU sovereignty and strategic autonomy in the supply of HALEU for its research reactors and medical radioisotope production. It provides an optimal long-term security of supply fully in EU control and is the recommendation of the working Group. It requires integrating a complex setup of actions, commitments and/or financing from the relevant EU, Member States, industries and end users.

In view of the challenges and time line for realisation for Option 3, Option 2 appears as a first intermediate step, while keeping its weaknesses in mind, namely its short time perspective, and not keeping competencies in the relevant technologies. Further, it requires deeper investigations in order to identify a suited instrument and pathway, investigating how to: build up the initial stock, finance the rolling stock, manage the storage (centralized versus several sites), define responsibilities and governance (ESA / Member States, operators), define rules for prices and HALEU allocation.

ANNEX 1

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ANNEX 2

Meetings

29.04.2021 1st Meeting WG European Production of HALEU – 3rd Mandate

18.05.2021 ESA AC

01.07.2021 2nd Meeting WG European Production of HALEU – 3rd Mandate

01.10.2021 3rd Meeting WG European Production of HALEU – 3rd Mandate

19.10.2021 ESA AC

09.12.2021 Video Conference Participants: Co-chairs, ESA

15.12.2021 Video Conference with ORANO, Participants: Co chairs, ESA, ORANO

12.01.2022 Video Conference with URENCO, Participants Co-chairs, ESA, URENCO

18.01.2022 4th Meeting WG European Production of HALEU – 3rd Mandate

21.04.2022 5th Meeting WG European Production of HALEU – 3rd Mandate

19.05.2022 ESA AC, Presentation Final Report WG European Production of HALEU – 3rd Mandate