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URENCO 1970–2020: FROM THE TREATY OF ALMELO TO ATOM AUSSTIEG

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This issue of *Nuclear Monitor* focuses on the uranium enrichment consortium Urenco. The author is Dirk Bannink from the Laka Foundation, a nuclear energy documentation and research center (www.laka.org). This is the English version of the original report (in Dutch, posted at tinyurl.com/urenco-dutch) plus a more detailed discussion of the A.Q. Khan network (with thanks to David Lowry for his help with this section). The report is part of the '50 Years Treaty of Almelo' project – a collaboration between Vedan Foundation, Enschede for Peace (NL), AKU Gronau, AKU Schüttorf, BBU (BRD), Close Capenhurst Campaign (UK) and the Laka Foundation.

The Treaty of Almelo was signed on 4 March 1970 – an agreement between the Netherlands, the United Kingdom and West Germany on setting up a company with the aim of enriching uranium: Urenco.

The origin of uranium enrichment is military and until then enrichment was primarily the monopoly of the United States and Soviet nuclear-weapon states.

Now, 50 years later, Urenco is a major player on the world market. But those 50 years did not go smoothly and even now the company is under pressure: not only because of the slowdown in the growth of nuclear energy, resulting in large overcapacity in the enrichment market and a shrinking order portfolio, but also due to the German *Atom Ausstieg* and the decline of nuclear energy in Urenco's traditional market: Western Europe.

This paper describes the development of uranium enrichment and the turbulent history of Urenco. It further analyzes current issues regarding Urenco and its uncertain future.

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CHAPTER 1: THE TREATY OF ALMELO

On March 4, 1970, the Treaty of Almelo is signed by West Germany, the United Kingdom and the Netherlands in the Dutch city Almelo. With this, a company is set up that will make uranium suitable for use in nuclear power stations by means of centrifuges, and a company that will produce and further develop these centrifuges.

1.1 Pre-signing

A declaration of principles was already drawn up between the three countries at the end of November 1968 on international cooperation in the enrichment of uranium.[1] On 11 March 1969 British, Dutch and West German ministers reached an agreement in London "on the basis of the favorable preliminary technical investigation" a joint uranium enrichment company: URanium ENrichment COmpany; Urenco.

The three countries each agree to build their own pilot enrichment plant: the British opt for the Capenhurst site where gas diffusion enrichment is already being applied and the German pilot plant will be built in the Netherlands for political reasons. Already a day after the agreement in London (on March 12, 1969) a piece of land was purchased in Almelo for the Dutch (and German) pilot plant. The Dutch partner in Urenco, Ultra Centrifuge Nederland NV (UCN), was established on November 4, 1969.[2]

Uranit was founded in West Germany on 6 August 1969 and will become the German partner in Urenco. In the UK, the UK Atomic Energy Agency – which is responsible for both the civilian and military nuclear program – will act as a partner until British Nuclear Fuel Limited (BNFL), its 100% subsidiary, is founded in 1971.

1.2 Signing and entry into force

The signing of the Convention takes place on 4 March 1970 in Almelo by the Foreign Ministers of the Netherlands (Joseph Luns), of the United Kingdom (Lord Chalfont) and of West Germany (Walter Scheel). Two companies were founded by signing the Treaty of Almelo: Urenco Ltd and Centec GmbH. Urenco Ltd, (with UCN, BNFL and Uranit shareholders as one-third each) acts as a marketing company representing the interests of the various enrichment plants and Centec (with the same proportion as BNFL, UCN and the German Gesellschaft für Nuklearverfahrestechnik mbh (GnV)) coordinates technological developments (R&D).

The United Kingdom ratifies the Convention on 26 March 1971; the Netherlands does this on 18 June 1971 and due to the ratification of West Germany on 19 July 1971 the Convention will automatically enter into force on that date. The Treaty includes the provision that, after it has been in force for 10 years, any contracting party, with a notice period of one year, can terminate the Treaty in writing (Art. XV). The "contracting parties" may also decide together to terminate the Convention (Art. XVI). Termination by one of the signatories would, according to the prevailing opinion, mean the end of the Treaty and thus the end of the attempts to curb the spread of secret ultracentrifuge enrichment technology. Threatening with cancellation therefore becomes a means of forcing decisions.[3]

1.3 Protest

Five days after the signing of the Treaty, a small demonstration is held in Almelo with about 50 people participating. On Pentecost, 16–18 May, there are 2500 people at the traditional annual tent camp of the Algemene Nederlands Jeugd Verbond (General Dutch Youth Association)[4] coincidentally that year in Almelo, where one of the spearheads is the demonstration against the "UC project" under the motto: "No A-bomb via Almelo".[5]

References:

1 "London, Bonn en Den Haag gaan samenwerken bij produktie verrijkt uranium" ("London, Bonn and The Hague to collaborate on production enriched uranium"), Leeuwarder Courant, November 26, 1968

2 De geschiedenis van het Nederlandse Centrifuge Project" ("The History of the Dutch Centrifuge Project"), J. Kistemaker, 1991

3 See for example the Brazil affair in Chapter 7

4 The ANVJ was a communist political youth organization, founded in 1945, with the aim of establishing one socialist youth movement. From an organizational point of view, the ANJV was independent, but politically it was affiliated with the Communist Party of the Netherlands. Within the ANVJ (and CPN) much attention was paid to West German "revanchism and atomic armament".

5 Jongeren manifestatie in Almelo" ("Youth manifestation in Almelo") in: De Waarheid, 19 May 1970, p1

Almelo enrichment plant, Netherlands.

CHAPTER 2: THE HISTORY OF URANIUM ENRICHMENT IN URENCO COUNTRIES

The origin and history of Urenco is closely linked to decades of research into uranium enrichment technology; and especially the development of ultracentrifuge technology. In this chapter we briefly describe that developmental history in what will eventually become the three Urenco countries: the Netherlands, Great Britain and West Germany.

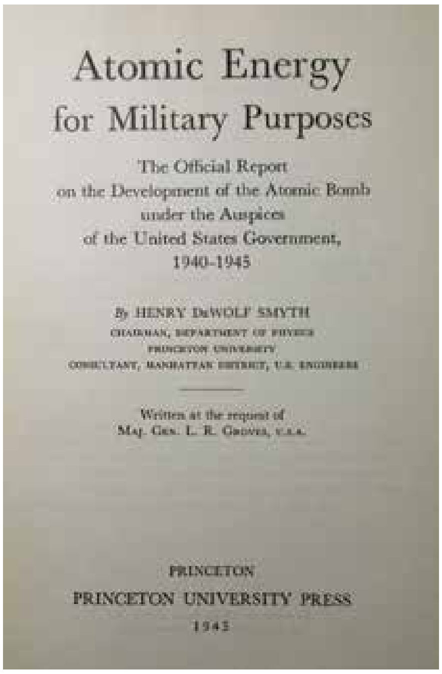
2.1 Manhattan project

In 1919, shortly after the existence of isotopes was experimentally confirmed, British scientists Lindeman and Aston suggested using centrifuges for the separation of isotopes. A number of tests with primitive centrifuges followed, but without success. After the American scientist Beams decided to isolate the centrifuge rotor in a thermal vacuum, isotopes of chlorine were successfully separated. In the Manhattan project[1], centrifuge was initially preferred as an enrichment technology, but in December 1943, after a number of centrifuges had exploded, they switched to gas diffusion technology.[2]

2.2 Smyth report

In the Smyth report[3] published in July 1945, Henry DeWolf Smyth described the two ways in which the Manhattan project obtained the material for the nuclear bomb: the production of plutonium by the bombardment of uranium-238 in a nuclear reactor and the enrichment of uranium by means of gas diffusion and gas centrifuge. For scientists who had not been involved in the Manhattan project, this was an ‘eye opener’.

Several countries started enrichment research based on this report, sometimes focused on diffusion and sometimes on gas centrifuges. Here we briefly summarize developments in the three Urenco countries.



Atomic Energy
for Military Purposes

The Official Report
on the Development of the Atomic Bomb
under the Auspices
of the United States Government,
1940-1945

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Written at the request of
Maj. Gen. L. R. Groves, U.S.A.

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1945

2.3 The Netherlands[4]

In 1947, the recently established FOM (Fundamental Research on Matter) began the development of an electromagnetic mass separator in the Zeeman laboratory of the Municipal University of Amsterdam. This makes it possible to separate small amounts of isotopes. Already in November 1953, a small amount (10 milligrams) of uranium was enriched to 8%.

In December 1954, Jaap Kistemaker started research into the development of uranium enrichment centrifuges in December 1954, after – he says – ‘accidentally’ attending a colloquium in Hamburg on the latest developments in the field of ultracentrifuge (about separating argon isotopes).

On March 10, 1961, the Dutch government, like the United States, the United Kingdom and West Germany, declared all work on the ultracentrifuge project “state secret.” As a result, FOM stopped doing this: they did not want to conduct a secret investigation. FOM was also of the opinion that it became less fundamental research and more applied research. Meanwhile, the centrifuge investigation was under fire from the (at that time still large) Dutch Communist party CPN and its daily newspaper *De Waarheid*. Kistemaker was accused of having worked for the German Cellastic during the war and still collaborating with German (former) Nazis on research into the German A-bomb “desired by the German revanchists”.[5]

The centrifuge investigation continued, but during the first half of the 1960s there was much doubt about progress and feasibility. Eventually in 1968 a test set-up of 70 ‘tollen’ (centrifuges) was put into use in Duivendrecht; due to lack of money, half the planned number. A few weeks later, most likely on December 17, 1968, all 70 centrifuges imploded in one go due to a gas breach. This accident was kept secret by the Netherlands during the negotiations with West Germany and the United Kingdom on the establishment of Urenco.

2.4 (West) Germany

In (West) Germany, research into uranium enrichment began in and actually before the Second World War mainly at the universities of Hamburg and Kiel. The chemist Groth had already developed a prototype centrifuge (together with Harteck and Beyerle) in Hamburg in the spring of 1941, which was further developed together with an arms company. Already in early 1943 it had succeeded in producing 100 grams of up to 7% enriched uranium.[6]

After the end of the Second World War, a number of restrictions were imposed on West Germany: much “natural science” research was prohibited and applied nuclear physics was at the top of that list. The Allied Kontrollrat (29 April 29 1946) introduced a complete ban on “Angewandte Atom-physik”. After the founding of the Federal Republic, this prohibition was taken over in Gesetz 22 of the Alliierten Hohen Kommission of 2 March 1950.[7]

As a result of the negotiations on the sovereignty of the Federal Republic, and due to the accession to NATO and the WEU (the Western European Union), the Paris Agreements were signed on 23 October 23 1954 and included in West German legislation in May 1955.[8] It prohibited the production of biological, chemical and nuclear weapons (Annex II), but also the possession of more than 2.1% enriched uranium.[9]

In practice, the handling of that prohibition in the different occupation zones in which Germany was subdivided developed very differently. In the British zone there was a very remarkable "interpretation" of the ban: as early as 1946, Beyerle was instructed to complete two uranium enrichment centrifuges that he had started during the war.[10]

Groth's research also continued virtually uninterrupted after the end of the Second World War; he was briefly interviewed in England, but was then allowed to continue his research, from 1950 at the University of Bonn and from 1955 again with Beyerle.

Parallel to this, German research took place in Russia, where a number of scientists (including Steenbeck and the Austrian Zippe) as prisoners of war made great progress with centrifuge development.

They developed a centrifuge that was more powerful but at the same time much smaller than the one that Groth developed in Bonn. From 1957 the Soviet Union invested in centrifuges for uranium enrichment, although the enormous gas diffusion enrichment plants remained in operation for decades. When the scientists returned to Germany in the late 1950s, research into the Zippe centrifuge continued in collaboration with industry in Germany. After the decision to declare centrifuge technology secret in 1961, the government decided to transfer the investigation to the Gesellschaft für Kernverfahrenstechnik, which later became one of the partners in Uranit, founded in 1969.[11]

2.5 United Kingdom

The United Kingdom was at the start of isotope separation by centrifuges: after all, it was the British scientists Lindeman and Aston who already suggested it in 1919. The internment in Great Britain of, among others, Hartbeck, who had done centrifuge research with Groth in Hamburg during the war, made people well aware of the scientific development of uranium enrichment by centrifuges.

The development of centrifuges, inter alia, through research in the German occupation zone, offered the British a first opportunity to become more independent of cooperation with the US. After all, the United Kingdom was also involved in the Manhattan project, and as a result uranium enrichment focused primarily on gas diffusion: as early as 1946 the construction of an enrichment plant based on that diffusion technology was commissioned. In 1950, a military site in Capenhurst was chosen as the location and in 1953 the production of first low enriched uranium started, and a year later already high enriched uranium was produced. Capacity increased considerably to 1,600 kg of highly enriched uranium in 1959. At the end of 1961, the company switched to the production of low enriched uranium for nuclear power plants and the gas diffusion plant was closed and dismantled in 1982.[12]

In addition to enrichment research through gas diffusion, British research into uranium enrichment by centrifuges was intensified from the 1960s. By 1966, centrifuge development had reached the point "where an efficient design had evolved" and started testing with a series of centrifuges. After two years, the centrifugation process proved to be viable and more economical than diffusion. The development of diffusion was then stopped and all British enrichment studies were concentrated on further improvement of the centrifugation process.[13]

Capenhurst enrichment plant, UK.

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1 The secret project, led by the United States, with the help of Canada and the United Kingdom that was to lead to the development of the atomic bomb during the Second World War.

2 R. Scott Kemp: "Gas Centrifuge Theory and Development": A Review of U.S. Programs, Science and Global Security, 2009, 17: 1, 1-19, DOI: 10.1080 / 08929880802335816

3 Officially titled: "Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb Under the Auspices of the United States Government, 1940-1945)" http://www.atomicarchive.com/Docs/SmythReport/index .shtml

4 Unless stated otherwise, the source for this part is: J. Kistemaker: "De geschiedenis van het Nederlandse Ultracentrifuge Project. Hoe een nieuwe industrie ontstond" ("The history of the Dutch Ultracentrifuge Project. How a new industry came about"), FOM Institute for Atomic and Molecular Physics, 1991

5 CPN: Kistemaker en de Duitse A-bom (CPN: Kistemaker and the German A-bomb), November 1960

6 Bernd-A Rusinek; Urananreicherung in Nordrhein-West-falen" ("Uraniumenrichment in North Rhine-Westphalia"), 2012 p4: http://www.rusinek.eu/wp-content/uploads/2012/02/Urananreicherung-in-Nordrhein-Westfalen-D%C3%BCsseldorfer-Bewerbungsvortrag.pdf

7 Paul Laufs; Reaktorsicherheit für Leistungskernkraftwerke 1: Die Entwicklung im politischen und technischen Umfeld der Bundesrepublik Deutschland" ("Reaction of the Leistungskernkraftwerke 1: The Entwicklung im politischen und technicalen Umfeld der Bundesrepublik Deutschland"); Springer Verlag, 2013 p32

8 See among others: Stephan Geier; Schwellenmacht: Bonns heimliche Atomdiplomatie von Adenauer bis Schmidt" ("Schwellenmacht: Bonn's secret Nuclear diplomacy from Adenauer bis Schmidt"), 2013 p17-21

9 Annex II at: http://www.fransamaltingvongeusau.com/documents/dl2/h2/2.2.5.pdf

10 Stephan Geier; "Schwellenmacht. Bonn's nostalgic Atom diplomacy from Adenauer to Schmidt"; 2013

11 Bernd-A Rusinek; "Urananreicherung in Nordrhein Westfalen", 2012 p4: http://www.rusinek.eu/wp-content/uploads/2012/02/Urananreicherung-in-Nordrhein-Westfalen-D%C3%BCsseldorfer-Bewerbungsvortrag.pdf

12 Britain's Nuclear Weapons, http://nuclearweaponarchive.org/Uk/UKFacility.html visited 19-01-2010

13 Urenco UK Centrifuge Enrichtment Plant Capenhurst, Corporate Brochure undated (1977)

CHAPTER 3: URENCO: COMPANY, CONTRACTS AND OUTLOOK

The main activity of the Urenco Enrichment Company is enriching uranium for energy companies to make uranium suitable for use in nuclear power plants. That enrichment is expressed in enrichment work or SWU (Separative Work Units); 1 SWU is equivalent to 1 kg of separation labor. An enrichment installation with a capacity of 1,000 tons of SWU per year can enrich uranium for around eight 1000 MW nuclear power plants annually. Urenco provides enrichment work at the four enrichment plants: Eunice (US), Capenhurst (UK), Gronau (D) and Almelo (NL).

3.1 Company structure

As we saw in Chapter 1, two companies were established with the signing of the Treaty of Almelo in 1970: Urenco Ltd and Centec GmbH. Urenco Ltd was a marketing company – the joint sales organization of UCN, Uranit and BNFL – that represented the interests of the various enrichment plants. Centec coordinated technological developments (R&D).

Protest against the Gronau enrichment plant, Germany, 1982.

A major reorganization followed in August 1993 whereby Urenco Ltd became a holding company of Urenco NL, Urenco Deutschland, Urenco UK and later also Urenco USA. Centec ends its existence and merges with the holding company. With this reorganization, Urenco Ltd becomes more than just a sales organization; it becomes the owner of the three (later four) enrichment plants. And the countries of the Almelo Treaty: the Netherlands (via UCN), Germany (RWE and E.On via Uranit), United Kingdom (via BNFL) then become the owner of Urenco Ltd. Until 1993, the individual Urenco enrichment plants were more or less "national" plants with Urenco Ltd as a joint sales organization. After the reorganization, the enrichment factories became part of the international consortium that the Contracting Parties own: with the result that the enrichment factory in Almelo became equally shared by the Netherlands, Germany and the UK, like those in Gronau and Capenhurst (and later Eunice).

Further legal restructuring is carried out in 2003, after which Urenco Ltd consists of two parts: Urenco Enrichment Company (UEC – which focuses on enrichment) and Enrichment Technology Company (ETC – which focuses on the manufacture of enrichment installations).[1]

The shares of Urenco Ltd are, as stated, one-third in the hands of the Dutch State through the Ultra Centrifuge Nederland NV[2] based in Groningen; one-third owned by the UK government through Enrichment Investment Limited[3] and one-third owned by Uranit UK Ltd,[4] in turn 100% subsidiary of Uranit GmbH based in Jülich. Uranit is in turn owned by the German energy companies E.On (50%) and RWE (50%).

Urenco Enrichment Company has four enrichment plants: Capenhurst (UK), Gronau (Germany), Almelo (the Netherlands) and Eunice, New Mexico (USA). A total of 1,500 people work in the four enrichment facilities.[5]

3.2 Enrichment Technology Company

ETC (Enrichment Technology Company Ltd.) could be seen as the "successor" of Centec. ETC was established in October 2003 and in 2006 ETC became a joint venture between the French Areva (nowadays Orano) and Urenco Ltd (or actually 50% Orano, 22% Urenco Ltd and 28% Urenco Deutschland). This was laid down in the July 2005 Treaty of Cardiff[6] on cooperation in the field of centrifuge technology between the three Urenco countries and France.

ETC has the exclusive responsibility to develop, produce, supply and install gas centrifuges on behalf of Urenco. In principle, all centrifuge enrichment plants that work with ETC technology in Europe and the United States are so-called black boxes; that is, the technology in the factories is not available to the enrichment companies that operate the factories. In practice, there are a few 'grey' areas where the ETC has shared a limited amount of compartmentalized classified information with the nuclear regulatory authorities that want assurance that the plants are safe.[7] ETC has plants in Almelo, Capenhurst and Jülich.

The stagnation in the capacity of the Urenco enrichment plants naturally also has consequences for ETC. Mass redundancies were announced in October 2012: about two-thirds of ETC jobs worldwide were lost: 1,400 out of 2000. For the Almelo plant, this means a loss of 240 out of a total of 800 jobs.[8] The price of enrichment work is currently too low to add or even replace production capacity.[9]

3.3 Reason for founding Urenco

The origin and history of Urenco is closely linked to the research and development of ultracentrifuge technology, now the most used method for uranium enrichment. During the 1960s and 1970s, there were high growth expectations of nuclear energy for energy production, with a consequent need for uranium enrichment capacity.

The history of Urenco is also closely linked to the desire of Western Europe to be independent of the US with regard to nuclear reactors and enriched uranium. The US did not authorize the reprocessing of nuclear fuel with US-enriched uranium; and that was almost everything at the time. However, Germany, the United Kingdom and France wanted to reprocess used nuclear fuel in order to remove the plutonium. Officially, they wanted to use plutonium in fast breeder reactors, such as Kalkar in Germany or Phenix in France. Breeder reactors were considered necessary because a shortage of uranium was expected, mainly due to the (apparently unrealistic) expected growth in (nuclear) energy consumption. By enriching the required uranium themselves, Western European countries were able to reprocess the spent fuel and thus develop their own industrial plutonium infrastructure. The two nuclear weapon options also remained open through an own enrichment industry, which could, after all, be obtained either by highly enriched uranium or by reprocessed plutonium.

3.4 Growth of Urenco

But by the time Urenco opened its first commercial enrichment plants, Capenhurst on 15 September 1977 and Almelo on 25 October 1977, it was clear that far fewer nuclear power plants would be built than was expected years earlier.[10] Instead of a shortage of enriched uranium, demand was then only half of global production capacity. Owing to the overcapacity and the large stocks of enriched uranium resulting in the low prices that the US and Russia demanded for enrichment work, it took until 1983 for Urenco to make a profit.[11] The money needed for research, development, construction and operation of uranium enrichment, centrifuges and enrichment plants have been largely paid for by the three governments involved.

Nevertheless, Urenco succeeds in conquering a place in a market that is already plagued by overcapacity and since the mid-80s, the company makes a profit every year.[12]

The growth of Urenco (from newcomer to global player) in those decades is due to two factors: enriching with ultracentrifuge technology is much cheaper due to the much lower energy consumption: “However, because Urenco has been able to offer competitive prices, its market share grew”, the Dutch Minister of Economic Affairs explains in 1987.[13]

In addition, the large enrichment plants in Russia and the US were from the Second World War or just after and in the 1980s, therefore, they were old and in need of replacement. But especially Urenco grew due to failures in the US. There, the policy was aimed at laser enrichment replacing the old diffusion plants. But the failure of that technology – along with the failure to realize replacement centrifuge enrichment capacity[14] – caused the US market share to fall dramatically and eventually evaporate completely. Urenco was able to take over that market almost entirely. The big competitor, the Russian Tenex, had much less access to the western market.

3.5 Privatization

Four years after the Dutch State had become 100% owner of UCN,[15] the Dutch government announced in May 2013 that it wanted to sell its shares.[16] The main reason given by the then Finance Minister Dijsselbloem is that the United Kingdom wants to privatize its shares, The German share is already owned by companies, so it makes no sense to hold a minority share.

Three years later, in November 2016, it is clear that the sales plans are stuck and have actually failed. The British government and the German shareholders also apparently abandoned the intention. The stumbling block seems be “safeguarding public interests”: the shareholders do want to sell but because of the sensitivity of the enrichment technology they also want to keep commitments from buyers and control over a number of aspects.[17]

It could be that the sale of Urenco will be high on the agenda again in the coming years, and then with a surprising buyer: the United States. The US government could be interested in Urenco because, in the absence of its own enrichment plant, it could get a shortage of enriched uranium that is not covered by international treaties and can therefore be used for its military program. The purchase of Urenco would be one of the options to get that “unobligated uranium”. (See chapters on tritium and HALEU).

Start-up costs

The Netherlands invested 1.2 billion guilders (€530 million) in Urenco from 1970 to 1983.[1] This amount roughly corresponds to the German government’s ‘contribution to Urenco in the period 1970–1992: 1.16 billion DM (€558 million).[2]

The financial contributions of the countries in the development of uranium enrichment in the period prior to 1970 are more difficult to trace, but it will be a total of several hundred million guilders for the Netherlands.[3] Slightly more precise figures are available for West Germany, but still incomplete: DM 30 million was spent from 1958 to 1967, DM 104 million in the following three years (1968–1970).[4]

1 Kansen op aanzienlijke nucleaire ontwikkeling” (“Opportunities for significant nuclear development”), Dagblad Tubantia 20-1-1984

2 http://dip21.bundestag.de/dip21/btd/18/019/1801910.pdf

3 See, among others, Nota Langman “Kosten kernenergie en kern-physica 1955-1969” (“Nuclear Energy and Nuclear Physics Costs 1955-1969”) in which uranium enrichment costs have been placed withïn the RCN, FOM and NIOF research institutes: https://kernenergieinnederland.nl/files/19720330-nota.pdf

4 “Geschichte der Kernenergie in der Bundesrepublik Deutschland” (“History of Nuclear Energy in the Federal Republic of Germany”), Wolfgang D. Müller, 1990 p527 / 8

3.6 Decline in earning capacity

If the period up to 2010 was Urenco's golden period, the following years should be seen as a turning point. Japan, Urenco's largest customer outside of Europe and the US, largely fell away after the nuclear disaster in Fukushima, but – more importantly – the expected "comeback" of nuclear energy did not take place. And that was not without consequences.

3.6.1 Shrinking production

In the meantime, the overcapacity on the enrichment market (see Annex II: The history of the enrichment market) is so great – largely due to the absence of the widely announced "nuclear renaissance" – that the company became concerned. The price of an enrichment unit (SWU) reaches a historic low, and a different business strategy is being investigated, the Dutch Minister of Finance said in January 2017: "The global demand for enriched uranium and hence the potential earning capacity for Urenco has fallen. ... Urenco is currently developing a new strategy in which the decline in the demand for enriched uranium plays an important role."[19]

It is clear that Urenco has adapted to the changing market: enrichment capacity and production have decreased in recent years, even with the commissioning of a fourth enrichment plant in the US. And actual production is much less than the permitted maximum capacity: planned and licensed new capacity has not been built. Taking into account the bulk of the capacity increase – Almelo in 2011[20], Gronau in 2005[21] and Eunice 2015[22] – was licensed in the years the 'nuclear renaissance' was predicted, the canceling of new production capacity is only logical since the nuclear revival never materialized.

Table I: Urenco: capacity and production 1976–2018 (in tSWU / y) [23]

Year	Licensed capacity	Production				
		NL	UK	D	USA	Total
1976	75	40	20			60
1980	460	220	190			410
1985	1,500	780	480	50		1,310
1990	2,600	1,100	800	400		2,300
2000	4,800	1,500	1,800	1,200		4,500
2012	19,400	5,500	5,000	4,200	2,200	16,900
2015	26,700	5,400	4,900	4,100	4,600	19,000
2018	26,700	5,200	4,600	3,900	4,900	18,600

3.6.2 Contracts and order book

Urenco has a worldwide market share of around 32% and is therefore the second largest uranium enricher: after the Russian Tenex, which has a market share of around 40%. These two companies therefore hold more than 70% of the world market. Orano (France) and CNNC (China) have 13% and 12% market share respectively. The remaining 3% are test installations in other countries.[24]

Urenco only discloses customer names in exceptional cases; nor is a list published in, for example, the Annual Report with companies (or nuclear power plants) for which Urenco is enriching uranium. In the last published Annual Report (for 2018), only "50 customers in 19 countries" are mentioned. That was different in the past: the Annual Report for 1985, for example, contained an overview with "Long Term Enrichment Customers."[25] But ever since then, less and less customer information has been made public.

As a result, a self-compiled overview of countries where enriched uranium from Urenco is used is the highest attainable. In this case it was helped considerably by a presentation in 2016 in South Africa by Urenco's Marketing and Sales manager about Urenco's "'pivotal role in the nuclear fuel cycle"'.[26]

With that information we come to the following countries: Belgium, Brazil, China, Germany, Finland, France, Japan,[27] the Netherlands, Ukraine, Slovenia, Spain, Taiwan, Czech Republic, United Kingdom, United Arab Emirates, United States, South Africa, South Korea, Sweden, Switzerland. But those are 20 countries and not 19. The reason may be that enrichment for the latest contract (signed in 2016 with the Ukrainian Energoatom)[28] is not yet taking place.

Enrichment contracts are generally concluded for 10 years or longer. The order book is €10.6 billion and "extends to the first half of the 2030s".[29] The Annual Report for 2010 reports an order book "in excess of €21 billion of future sales."[30] A clear decrease and again an indication that nuclear energy is in the doldrums and with it the enrichment industry. Although Urenco's market share has risen slightly in that period (see above), this indicates more of a shift in market share within the group of existing producers than of market growth.

Table II: Development of installed nuclear capacity

Year	Number of nuclear reactors	Totale capacity MW
1960	15	1087
1970	84	17,656
1980	245	133,037
1990	416	318,253
2000	435	349,999
2010	441	375,277
2020 *	447*	395,626**

* These are figures from the IAEA, which also includes the 24 Japanese reactors that have been out of operation for almost 9 years, but for which no decision has yet been made as to what will happen to them. In reality, therefore, there are more than 20 fewer nuclear plants in operation as listed here

** The capacity is from the end of 2019 (the latest figures on the IAEA webpage) https://pris.iaea.org/PRIS/home.aspx (as of 8 Feb. 2020) and includes the 24 Japanese nuclear power plants.

3.6.3 Urenco market share

Urenco's market share grew from 7% in 1985[31] 19% in 2004[32], 29% in 2011[33] to 32% now.[34] Clearly visible is a flattening in the growth figures and it can be expected that the market share will fall rather than rise in the coming years. There are a number of reasons for this: the traditional market of Urenco (Western Europe – minus France – and North America) is stagnating, nuclear power stations are being built very slowly while many nuclear power stations will be closed.

The growth market for nuclear energy is located in the Far East and especially in China, with its own enrichment industry. If, in addition, nuclear power stations are to be built, they will be built almost exclusively by the Russian Rosatom, with which enrichment contracts will automatically go to the Russian Tenex. And finally: the US will in any case set up its own enrichment industry, necessary to produce enriched uranium that can be used for military purposes.

Table III:
SWU production (in tonnes of SWU per year) [35]

Country/Company	1978	1998	2019
US (without Urenco)	27,300	19,400	-
Russia (Soviet Union)	20,000	20,000	23,600
France (Eurodif)	600	10,800	7,500
Urenco	400	3,900	18,600
China	400	800	7,100
Other			600
Total	48,700	55,800	57,400

3.7 Trading in enriched uranium

Urenco always attaches great importance to making it clear that it does not own the uranium it enriches: the uranium is and remains the property of the customer; Urenco only provides a service: enrichment work. However, that does not mean that Urenco itself does not have uranium; it even probably possesses enriched uranium. The depleted uranium, which arises from enrichment, becomes the property of Urenco. Convenient for the customer, who, because of thisarrangement, has no responsibility for the safe and long-term storage of this waste product. That depleted uranium can be re-enriched again and sometimes that happens; in its own enrichment plants or at a competitor such as Tenex in Russia. What happens next with that uranium is opaque, but the only possibility is that Urenco itself also trades in (enriched) uranium.

Urenco actually never reveals which of the four factories is used for which customer; that depends on the capacity. There also appears to be a constant flow of uranium transports between the various enrichment plants; very broad permits make that possible. Such permits, from which detailed transport flows cannot be distilled, also ensure little transparency in this area. Transport overviews have occasionally been published by the German parliament and the state of Nordrhein Westfalen,[36] but such lists have not (yet) been made public for Almelo, Capenhurst and Eunice.

3.8 Stable isotopes[37]

In the new business strategy announced in 2017 "in which the decline in the demand for enriched uranium plays an important role", the stable isotopes department could play an important role. Centrifuges are used in this department to purify certain non-radioactive (stable) isotopes.
In addition to industrial applications, these stable isotopes mainly serve as a raw material for the production of short-lived radioisotopes that are used in imaging technology in medical diagnostics and in cancer therapies. These short-lived isotopes can then be produced in nuclear reactors, but also, and increasingly, in cyclotrons and other particle accelerators; without nuclear fission, uranium and highly radioactive waste. The raw material required for the production of medical isotopes are specific stable isotopes.

Many elements are naturally present as a mixture of one or more isotopes. For example, natural molybdenum, like natural uranium, contains various isotopes. One particular isotope thereof serves as a raw material for the production of a certain type of medical isotope. To get it as pure as possible, it must be enriched. This enrichment can be done in all kinds of ways such as distillation and diffusion, but also with ultracentrifuge.

That is what happens in Almelo too, because they have technology for enrichment. Urenco started enriching stable isotopes in 1990 in Almelo as a research and development activity. In the years that followed, the product portfolio grew steadily to more than 30 isotopes of 10 elements for all kinds of medical and industrial applications. Urenco Stable Isotopes has been operating as an autonomous business unit within Urenco since the mid-1990s. The production of these types of isotopes takes place in separate installations. Therefore, radioactive contamination cannot occur; it is a completely separate part.

There is nothing wrong with this production, but it does not have to be connected in any way to Urenco or to the nuclear industry in general. Although this business unit seems to be growing fast, Urenco does not want to make any statements about the turnover of it or its percentage within total business turnover.

The Stable Isotopes department is undoubtedly one of Urenco's responses to the decline in "global demand for enriched uranium and thereby the potential earning capacity of Urenco", as noted by the Dutch government.[38] But in addition, production for medical purposes is played out in the media as justification for the nuclear industry.[39]

3.9 Sponsoring; buying consent

What immediately stands out on the websites of the various Urenco enrichment plants is the attention to the local community. That is called “Supporting our local communities”. Urenco invests extensively, but relatively small amounts, in organizations in the area: from billiards clubs, sports clubs, local media, animal ambulances to New Year’s concerts. A commendable aim? Perhaps. And certainly important for the local grocer who has to convince the neighbors to buy fruit and vegetables at his / her store. But Urenco does not have customers like that in the local community at all. And so this is about something else: buying consent; building goodwill and smothering critical voices, by creating a financial dependence.

To which problems this can lead becomes clear in 2013 when the public library in Almelo cancels an exhibition about Urenco and the major demonstration ‘35 years later’ at the last minute.[40] Reason: the library is sponsored by Urenco and the director therefore thinks it is “a matter of decency and based on our partnership not reasonable to cooperate”. There is brief commotion in the local media,[41] but that quickly ebbs away. However, the impression remains that if you do not want to jeopardize your financial contribution, one should not accommodate criticism about Urenco. Buying consent.

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CHAPTER 4:
THE URENCO ENRICHMENT PLANTS

The Urenco Enrichment Company has enrichment facilities on two continents in four countries: from the outset in Capenhurst (United Kingdom) and Almelo (Netherlands); from 1985 in Gronau in Germany and from 2010 in Eunice, in the United States. Below are the details of the different locations. The policy regarding depleted uranium, which varies from location to location, is described in chapter 5.

4.1 Urenco NL: Almelo

For the Dutch location of the enrichment plant, Almelo is preferred to a site between Gulpen and Maastricht, officially due to the particularly firm and vibration-free surface. But the site is also owned by one of the shareholders of UCN: Philips. The site in Almelo is already purchased on 12 March 1969, one day after the signing of the agreement-in-principle between West Germany, the United Kingdom and the Netherlands. The construction of the centrifuging plant begins on 26 June that year and UCN, Ultra Centrifuge Nederland, is set up on 4 November. UCN is a collaboration between industry and the Dutch state, but that will change quite quickly.

When the treaty was signed in Almelo on 4 March 1970, the site a few kilometers away was already under development. Already in November 1970, SP1, the first Separation Plant, with a capacity of 25 tSWU / y was put into operation and the German pilot plant SP2, which is also located in Almelo, with a capacity of 5 tSWU / y, followed in October 1972.

At the beginning of the 1970s it was already clear that the Dutch centrifuges considered to be superior[1] were not satisfactory and the evaluation committee of Centec (responsible for the development and construction of the centrifuges) therefore wrote off the Dutch design in 1973. Almelo continues with the German G2 design, according to German specifications.[2]

In the meantime, uranium enrichment and especially cooperation with Germany are under considerable pressure from publications from mainly the Communist Party of the Netherlands (CPN): it would give the German revanchists the opportunity to build an atomic bomb.[3] This claim, not at all out of thin air as it turns out,[4] is swept away as cold war rhetoric. But a number of other “affairs” in the late 1970s are causing huge the opposition (also within parliament) against UCN and the future of the plant is under pressure.

In 1974, nuclear fuel that was enriched in Almelo was loaded at the Dodewaard nuclear power plant: it was the first contractual delivery of enriched uranium[5] and on 25 October 1977 the first commercial department, the SP3, was officially commissioned.[6]

At the time UCN receives the license for expansion to 1000 tSWU / y (SP4) on 8 February 1978, this is on the eve of the largest demonstration ever at any Urenco plant. The demonstration on March 4 that year with the central slogan “No expansion of the UCN” attracts 45,000 to 50,000 people.[7] An important reason for the large participation is the planned delivery of enriched uranium to the military dictatorship in Brazil.

At the end of the 1970s and in the 1980s, UCN Almelo continued to attract negative media attention, among other things due to Khan’s nuclear espionage and the enrichment of South African-stolen uranium from occupied Namibia,[8] but the company gradually disappears out of the spotlight.

Because the industry announced in 1976 that it had lost faith in the centrifuge factory and no longer wanted to invest, the costs of capacity expansion were entirely borne by the Dutch State. As a result, the share of industry is falling from 45 to 1.1%. In October 2009, the Dutch State buys the last 1.1% of the shares for an amount of 17 million euros.[9]

Table III: Shareholders Ultra Centrifuge Nederland (in%)

Year	Industry	Dutch State
1970	45 *	55
1978	1.1	98.9
2009	-	100

* Industry 45%: RSV, VMFStork 7.5% each; Philips, Shell, DSM 10% each

Although Urenco as a whole is expanding and the capacity of the Almelo plant is also increasing considerably, that does not mean that the Almelo branch is going strong.[10] One week after the Chernobyl nuclear disaster, an enormous extension permit is being applied for, but the nuclear energy market is collapsing due to that nuclear disaster. Although the 3500 tSWU / y license was issued in March 1987, UCN announced at the beginning of 1988 that it would not extend. What follows are years of uncertainty about permits: the Council of State nullifies a number of licences and the government is issuing a number of temporarily permits to grant continuation of production.

After the very delayed opening of SP5 in March 2000 (bringing the capacity to 2500 tSWU / y), UCN will only be granted another permit for 3500 tSWU / y[11] in October 2005 and another increase in capacity to 4500 tSWU /y will be licensed in 2007. Just before the Fukushima nuclear disaster, UCN is applying for a permit for 6200 tSWU / y. Although that permit is granted on 28 October 28 2011, once again the expansion will fall far behind schedule: in 2018, production was 5200 tSWU / y; 300 tons less than in 2012.

4.1.1 Aeronamic

The company Aeronamic is a collaboration between UCN and the University of Twente.[12] It was created in 1988 as a spin-off of Urenco, called Urenco Aerospace and applied the Urenco knowledge of high-speed machines for aviation purposes. Aeronamic became independent in 2005 and is currently an "internationally leading player in the aviation industry."[13] A major customer is the defense industry for the production of the F-35 fighter jets.

4.2 Urenco UK: Capenhurst

As a result of the partly military character of the British enrichment industry, Capenhurst remained for a long time a shared property with two owners: British Nuclear Fuel Ltd (who worked for the British military sector and was also the British shareholder of Urenco) and Urenco Ltd.

Uranium has been enriched in Capenhurst since 1953,[14] but from 1968 on the emphasis shifts more and more from the development of diffusion to that of centrifuges.[15]

In 1972, a centrifuge test installation with an enrichment capacity of 14 tSWU / y was commissioned in one of the existing gas diffusion halls.[16]

The first commercial centrifuge facility in Capenhurst, the E21, came into operation in 1976 and was officially commissioned on September 15, 1977[17]; it was the first in the world to commercially enrich uranium by means of centrifuges. With the commission of the E22 in 1982, capacity was expanded and with the E23 in 1997.[18] The E23 is by far the most important component and produces approximately 80% of the total capacity in Capenhurst.[19]

The Capenhurst A3 production part opened in 1984 was built for military purposes (submarine fuel; the contract for construction came from the Royal Navy)[20] but never produced highly enriched uranium; but it did produce uranium that was enriched more than 5% for export to the US to be enriched further to highly enriched uranium or to be exchanged with the US for highly enriched uranium for military purposes.[21]

According to the Treaty of Almelo, it is possible for the UK, as a nuclear-weapon state, to further enrich uranium enriched in a Urenco installation for use in nuclear weapons.[22] However, the British government has stated that if it does – it will only do so with enriched uranium from the 'British' Urenco plant in Capenhurst and not with uranium enriched at Almelo or Gronau.[23] Or as the Dutch then PvdA MP Relus ter Beek reacted when there was some concern about of the English plans: "The technique of the centrifuge method is owned by each of the countries and they may therefore use it for their own military purposes."[24]

The years 1991/92 are economically disastrous for Capenhurst. At the beginning of 1991, the Ministry of Defense terminates the contract with the BNFL plant, which costs 400 jobs[25] and a year later another 550 jobs disappear "because of the collapse of the world market since the end of the Cold war."[26] Since 2012 Urenco UK – the British subsidiary of Urenco Ltd – is the only permit holder of the site. According to the latest figures,[27] Capenhurst has an enrichment capacity of 4,600 tSWU / y.

In Capenhurst, the Urenco Tails Management Facility was put into operation in 2019 to convert depleted uranium hexafluoride into a more stable solid oxide form (more about this in Chapter 5 on depleted uranium).

In addition, the Urenco site in Capenhurst will see the storage of dismantled nuclear reactors (RPVs: Reactor Pressure Vessels) from nuclear submarines, the British Ministry of Defense (MOD) announced in July 2016.[28] CNS (Capenhurst Nuclear Services – a Urenco subsidiary and renamed Urenco Nuclear Stewardship at the end of 2017[29]) will be responsible for storing the RPVs until there is a [geological] disposal facility. The establishment of such a disposal facility will, as in many other countries, take some time in Great Britain.

4.3 Urenco Deutschland: Gronau

Whether it was the result of restrictions on the production of nuclear fuel on German territory after the Second World War or the ongoing negotiations on West-German accession to the Non-Proliferation Treaty,[30] in any case the three countries decided the German enrichment plant to be built on Dutch territory: namely on the Urenco site in Almelo. In September 1971, the Dutch Ministry of Economic Affairs issued the Nuclear Energy Act license for the construction of the SP2: Separation Plant 2. In July 1974, the license for the construction of the joint German-Dutch 200 tSWU / y enrichment plant, the SP3, followed.

In 1978 the governments of the three Urenco countries agreed to build an enrichment plant in Germany, based on (of course secret) agreements in the Joint Committee from 1974 and 1977. The agreement would be that if the total Urenco installed capacity reached 2,000 tSWU / y the construction of an enrichment plant in West Germany would be possible. The Dutch parliament had in fact agreed in June 1978[31] to expand capacity of Urenco Almelo, on the assumption that it would prevent the construction of a West German plant.

Founded in August 1969, Uranit applied in March 1978 for the first permit for the construction of the enrichment plant in Gronau, 40 km from Almelo.

In 1985 the first part of the enrichment plant with a capacity of 40 tSWU / y went into operation and in 1989 400 tSWU/y was reached and an extension permit up to 1,000 tSWU / y was also issued. Following a license for capacity expansion to 1,800 tSWU / y in 1997, Urenco Gronau received the current license for an enrichment capacity of 4,500 tSWU / y in February 2005.[32] At the same time, an amendment was made to the maximum percentage uranium can be enriched: 6% uranium 235, which was 5% since the commissioning in 1985.[33]

4.3.1 Urenco and the Atom Ausstieg

Urenco's enrichment plant has been kept outside the German Atom Ausstieg (nuclear power phase-out), just like the nuclear fuel elements production plant in Lingen. On 27 February 2018, the fractions of Bündnis 90 / Die Grünen and Die Linke in the German Bundestag submitted a bill[34] to include the nuclear facilities in Gronau and Lingen into the Ausstieg.

The Atom Ausstieg only concerns nuclear power stations, the last of which (also in Lingen) must be closed in 2022. The bill did not make it: it was voted down in March 2019.[35] But the call for a consistent and comprehensive Ausstieg only grew and in December 2019 it was announced that Environment Minister Schulze is working on a ban on exports of nuclear fuel elements from Lingen to 'grenznahe' nuclear power stations. This would concern nuclear power plants that are more than 30 years old and less than 150 km from the German border.[36] Such a prohibition is mainly aimed at the reactors Tihange in Belgium and Fessenheim in France; nuclear power plants that have serious doubts about safety. But with a ban on nuclear fuel elements, an export ban for enriched uranium for the same category nuclear power plants seems only a logical next step. In total, such a ban would affect more than 10 nuclear reactors, including the one in Borssele.[37]

For many years now, Urenco Gronau is the Urenco plant where most protests take place. Since the end of 1986 (!) so called "Sonntagspaziergang" takes place on the first Sunday of every month; the 400th protest-walk was on 5 January 2020.[38]

4.4 Urenco US: Eunice

In the spring of 2010, the Urenco enrichment plant in Eunice, in the US state of New Mexico, was put into operation. The National Enrichment Facility is owned by Urenco's daughter Louisiana Enrichment Services (LES). The "Establishment, Construction and Operation of a Uranium Enrichment Installation in the United States" was made possible by the Treaty of Washington signed in July 1992 and the use of "Gas Centrifuge Technology in the United States of America" by the Treaty of Paris.

LES had already applied for a permit in 1989 for an enrichment plant in Homer, in the state of Louisiana, which should have been operational in 1996. But due to strong local opposition – organized in Citizens Against Nuclear Trash – there came no permit and for a special reason: CANT reasoned that the choice of location, Homer, was based on "environmental racism". Of all the hundreds of potential locations that LES looked at for its plant, Homer was the one with the highest percentage of African Americans and with the lowest incomes on average. And that argument from CANT was taken up by the nuclear regulator, the Nuclear Regulatory Commission (NRC), which refused the permit.[39] The first time that environmental justice had a determining role.

But the US market, with 100 nuclear power plants, the world's largest market, continued to lure, and after a second failed attempt in 2002 in Hartsville, Tennessee,[40] LES made another attempt in the state of New Mexico. In 2006, Urenco received a permit for an enrichment plant with a production of 5,700 tSWU / y[41] five miles (8 km) outside of Eunice. The first uranium was enriched in June 2010[42] and in March 2015 Urenco USA received a permit for a maximum capacity of 10,000 tSWU / y,[43] with which it could be the largest Urenco enrichment plant. But here too the actual production is a lot less: by the end of 2018 they had not even achieved the production of the old permit: 4,900 tSWU / y.[44]

In February 2019, Urenco USA announced that it wants to produce HALEU.[45] HALEU (High Assay Low Enriched Uranium) is 19.75% enriched uranium. The plant is allowed, according to its permit, to enrich to a maximum of 5%, but so far produced LEU at levels of approximately 4.5%. But the facility can be converted to enrich up to 19.75%.[46] That percentage is still called "low-enriched" uranium. (See chapter 6: HALEU)

Urenco's Treaties

Treaty of Almelo[1]

Signed 4 March 1970; entry into force 19 July 1971
Agreement between the Troika states (Germany, the Netherlands and the United Kingdom) for the development and operation of the gas centrifuge process for the production of enriched uranium. It must primarily deal with non-proliferation issues: to prevent other than then existing nuclear weapons states to use this this technology to produce nuclear weapons. The Treaty also regulates the supervision by the three governments in the Joint Committee, and at the same time stipulates that all documents will remain secret, without public access.

Treaty of Washington[2]

Signed 24 July 1992; entry into force 1 Feb 1995
Agreement between the Troika states (Germany, the Netherlands and the United Kingdom) and the US government. The treaty allows the transfer of classified (secret) information to the US – necessary for Urenco to open a uranium enrichment plant in the US. The treaty stipulates that the conditions that are agreed in the Treaty of Almelo also apply to the US.

Treaty of Cardiff[3]

Signed 12 July 2005; entry into force 1 July 2006
Agreement between the Troika states and the French government: the treaty allows the creation of Enrichment Technology Company; the 50/50 joint venture with Areva (now Orano): ETC will develop and build centrifuges. Urenco and Orano agree to ensure that they remain competitors in the field of enrichment.

Treaty of Paris[4]

Signed 24 Jan. 2011; entry into force 31 Jan. 2012
Agreement between the Troika states, the French government and the US government that allows the transfer of ETC technology in the US. This treaty is explicitly not about the Urenco enrichment plant in Eunice, which is from Urenco, but about any new enrichment facilities to be built in the US that can be equipped with technology developed by ETC and therefore essentially from Urenco.

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CHAPTER 5: DEPLETED URANIUM: STORAGE AND DUMPING IN RUSSIA

The nuclear energy chain produces huge amounts of radioactive waste. Often there is only attention for the highly radioactive waste from a nuclear power plant, but with every step in the cycle waste streams are released. This starts with the mining of uranium, where large quantities of uranium ore are left behind and in which 90% of the radioactive radon gas is present, with all its consequences for the local population. Even with enrichment, the vast majority (85%) remains behind as waste: depleted uranium (DU). There are differences between Urenco plants about what happens with DU, but dumping of large quantities in Russian Siberia is always one of the options

5.1 DU: Origin and quantities

For one 1,000 MW power plant (the Dutch Borssele nuclear power plant is about half), about 29 tons of UO_2 (uranium dioxide) are needed per year. That is 38 tons of enriched UF6 and to get that, 306 tons of natural UF6 is needed (and about 120 tSWU). For 306 tonnes of natural UF6, it is necessary to extract approximately 108,482 tons of uranium ore from the ground. Depleted uranium (DU) is the residual product – waste – from enrichment. Every kilo of enriched uranium (with an enrichment rate of 3.6%) yields more than 7 kilos of depleted uranium. To enable enrichment through gas centrifuges, the uranium must be converted to uranium hexafluoride or UF6. UF6 is gaseous at a relatively low temperature (56° C).

Huge amounts of depleted uranium have arisen as a result of 70 years of uranium enrichment; the vast majority in the chemical form of uranium hexafluoride.

Theoretically, it is possible to extract even more fissionable uranium (U-235) from the depleted uranium, which contains on average still 0.2–0.3% U-235. This re-enrichment depends on a number of economic factors: the price of "fresh" natural uranium, the price of enrichment and, nowadays, an excess of enrichment capacity (overcapacity). Re-enrichment is not effective in reducing the volume of depleted uranium, but it can be used (and is also used) to move those volumes: e.g. from Western Europe to Siberia.

The depleted UF6 is stored in containers awaiting a decision on what to do with it. At present, around two million tonnes of depleted UF6 are stored on factory sites worldwide, of which 800,000 tonnes (about 41%) in Russia[1] and 700,000 tonnes in the US.[2]

A well-known civilian application of depleted uranium is its use as a counterweight in, for example, aircraft or ships. In the military industry, depleted uranium is mainly used in anti-tank munitions and in the armor of tanks and other armored vehicles. The US Army in particular has used large quantities of depleted uranium, with disastrous consequences for people and the environment.[3] Russia also uses part of its huge supplies in military systems; recently also in new type of anti-tank ammunition: the Svinets-2.[4]

5.2 Uranium hexafluoride

Uranium hexafluoride is a highly toxic radioactive substance that becomes gaseous at a low temperature, 56 degrees Celsius, and can then easily spread in the air. It is also a substance that attracts water. When UF6 and water (e.g. in the air) come together, two different toxic substances are formed: hydrogen fluoride (HF) and uranyl fluoride (UO2F2). Hydrogen fluoride burns the eyes, mucous membranes and respiratory organs and can cause pulmonary edema. Even with short-term exposure (10 minutes) to a concentration of 800 mg / m3, this can result in death. Hydrogen fluoride is gaseous and spreads in the air. Uranyl fluoride is radioactive. It is also very toxic; it is corrosive and harmful by inhalation, ingestion or skin absorption. Ingestion or inhalation can be fatal. Effects of exposure can be delayed.[5]

5.3 Deconversion in Urenco's TMF

The conversion of uranium to uranium hexafluoride is called conversion. There are only a few factories worldwide that perform conversion. To store depleted uranium for a long time, it is necessary to convert the uranium hexafluoride back to a (chemically!) stable substance: uranium oxide or U3O8. This is called deconversion and is now happening, for Urenco's European enrichment factories, in Pierrelatte in the south of France. But that will change because in June 2019 the Tails Management Facility (TMF) was officially opened in Capenhurst. The TMF was supposed to go into operation for £400 million in 2015, but that became around £1 billion[6] and due to start-up problems, the TMF was not yet in use at the official opening: "operations are planned to start in 2020," Urenco stated.[7]

The nominal deconversion capacity of the TMF is 14,000 tonnes per year, but that can be expanded.[8] One tonne of UF6 becomes about 0.8 tonnes of U3O8 after deconversion. When the depleted UF6 transports from Almelo and Gronau will go to Capenhurst instead of Pierrelatte, is not yet known in the case of Almelo[9] but for Gronau this is certainly not earlier than 2024.

5.4 Storage of depleted uranium

Once the UF6 has been converted to U3O8, re-enrichment is no longer feasible, but other civilian or military applications remain possible. The U3O8 converted from Capenhurst (and now Pierrelatte) from Almelo and Gronau should be transported back to the Netherlands and Germany where it should then be stored. But what happens with it varies across Urenco countries.

5.4.1 Storage of DU in the Netherlands

Urenco has a permit to store 65,000 tons of natural and depleted uranium and 2,750 tons of enriched uranium UF6 at the Almelo site.[10] That is, according to Urenco, the amount that is required for continuous operations. From 2004, the Dutch depleted U3O8 that comes back from Pierrelatte after deconversion[11] is stored at the Covra in Zeeland, the Central Storage for Radioactive Waste in the Netherlands. Before that it was stored as UF6 in the open air on its own Almelo site[12] and in the period 1995–2009 more than 50,000 tons were exported to Russia. In the meantime, two special storage halls (Depleted uranium Storage Building; VOG-I and II) have been erected in Zeeland, in which the waste is stored until it is disposed of in the – as yet unknown – permanent disposal facility. According to the latest information, the Covra contains 16,020 cubic meters (m3) of depleted uranium and an average of 1,000 m3 is added annually.[13] That is 4,577 containers with a volume of 3.5 m3. The total weight of U3O8 is then almost 49,000 tons; slightly more than 10 tons on average per container.[14] Urenco pays a fixed price for the storage of depleted uranium at the Covra.

All depleted uranium must be stored in the final disposal facility; foreseen in the Netherlands in 2130. For permanent storage the depleted uranium is 'reconditioned' and repacked in the equally large Konrad Type II container.[15] Covra expects that in 2130 9060 Konrad Type II containers with depleted uranium will go to the final storage.[16] That is over 90,000 tons of depleted uranium, half of which is already present at the Covra.

5.4.2 Storage of depleted uranium in Great Britain

The Urenco plant in Capenhurst stores the depleted uranium in the form of UF6 on its own site and has a permit for the construction of a hall for the storage of U3O8 for the next 100 years.[17] From Capenhurst about 20,000 tons[18] of depleted uranium were exported to Russia in the period between 1995 and 2009 "to limit the quantities of tail stocks stored at Capenhurst"[19] and again from 2016 on exports large quantities of depleted uranium to Russia.[20] Exactly how much depleted UF6 is stored on the Capenhurst site is unknown. An estimate is 90,000 tonnes, part of which is also from the gas diffusion enrichment plant.[21] The local Close Capenhurst Coalition appealed to the Freedom of Information Act in 2016 and asked the regulator (ONR) about such details. The answer was amazing: figuring out that information and whitening business-sensitive information would cost between £600 and £900.[22] To be paid by the Coalition.

5.4.3 Storage of DU in Germany

Gronau has a permit for the storage of a total of 36,000 tonnes of UF6 (both natural, depleted and enriched) in the open air on site and sends the depleted UF6, just like Almelo, to Pierrelatte for deconversion. Since 2014 there is on the Gronau site a special storage hall (capacity 58,000 tonnes) in which the U3O8 coming back from France can be stored until there is a final disposal possibility.[23] The remarkable fact is that the storage facility is still not being used and, according to the ministry, is not going to be used before 2024.[24] Where all UF6 and U3O8 from Gronau is, is unclear: a large part has been 'exchanged' in a slurred deal with Capenhurst. In the period 1995–2009, a total of 27,300 tonnes of depleted UF6 were dumped in Russia[25] and another 6,000 tonnes were transported to Russia in 2019 alone. Urenco Germany announces that transports to the deconversion facility in Capenhurst will not take place until the U3O8 storage hall in Gronau has been put into use[26] which may take a while.

5.5 Dumping DU in Russia

In October 2019, questions in German parliament[27] revealed that Urenco was again exporting depleted uranium to Russia. Officially for re-enrichment, but due to the enormous Russian stocks of depleted UF6, there are serious doubts as to whether re-enrichment actually takes place. However, even if the depleted uranium is re-enriched – according to the contract to natural level, that is 0.7% – only a small part (10–20%, depending on the amount of U-235 that was still present) comes back to Urenco , the rest (80–90%) of the waste remains in Russia. For Urenco, as we concluded earlier, a handy and inexpensive way to get rid of huge amounts of radioactive waste.

5.5.1 New contract

According to the contract signed in 2018, 6,000 tonnes of depleted UF6 can initially be transported to Russia in the 2019–2020 period for re-enrichment. But according to an addition to the contract, another 6,000 tons from the three Urenco plants can be exported to Russia in the years 2019–2022.[28] At the end of 2019, 6,000 tons were transported from Gronau to Russia via the port in Amsterdam: ten transports of 600 tons each. Which would have already met the first part of the contract.

Urenco denies that depleted uranium from Almelo also goes to Russia, but since there are many transports between the different Urenco enrichment plants, under opaque permits, it is unclear, but not impossible, that depleted uranium from Almelo will eventually via Capenhurst or Gronau. end up in Russia. But even when it does not include Almelo's uranium, it is all uranium from Urenco and the Netherlands owns and is responsible for one-third of that waste, regardless of its location. Urenco Netherlands did in fact receive a transport permit in 2019[29] for the transport of depleted uranium to the Russian nuclear fuel element factory PJSC "MSZ" in Elektrostal. The required export license has not yet been issued for this (as of 31 Jan. 2020). This depleted uranium should be used there for the production of fuel. It is a strange contract, because given the huge stocks of the material that Russia itself has, the price and conditions for the purchase of depleted uranium from the Almelo plant must be very advantageous for Russia.

5.5.2 100,000 tonnes to Russia earlier

It is not the first time that Urenco is transporting depleted uranium to Russia for re-enrichment: a contract was concluded with the Russian company Tenex in June 1995 to produce "uranium with the natural concentration of fissile isotopes" in the Russian enrichment plants.[30]

That Urenco statement was false: answers from parliamentary questions in 2008 showed that also 4.5% enriched uranium came back from Russia.[31] In June 2009, Tenex announced that it would not extend the contract due to economic infeasibility.[32] Economic reasons are, however, only half of the story, meanwhile the resistance in Western Europe – just like in Russia – had grown so much that every transport provoked more protest. In total, around 100,000 tonnes of depleted UF6 were transported to Russia during that period (1996–2009).[33]

Of those 100,000 tons, more than half came from Almelo: in the period 1996–2007 it was already 53,683 tons. In the same period, 10,282 tonnes went to Pierrelatte for conversion to U3O8.[34] "According to Urenco, economic reasons determine which option is preferred by Urenco," according to Dutch minister in November 2007.[35] Well, that is obvious: without the export of huge amounts to Russia, the amount of depleted uranium stored at the Covra would have been already more than twice as much as currently stored. Instead of stored in the special facilities VOG III and IV, it now lies in Siberia and the Urals. The Council of State agreed with Urenco and found that it was a raw material and not radioactive waste.[36]

Following the resumption of transports to Russia in 2019, a number of parliamentary debates have taken place in the Dutch parliament. In Germany it is really a "hot topic" but not in Great Britain.

With these transports to Russia, the Dutch government is happy to hide behind the argument that international organizations determine whether this is permitted and that the Netherlands only deals with transport safety. The supervisor appointed by the Almelo Convention, the Joint Committee, would also not be responsible and therefore could not prohibit it. But in the Treaty of Almelo the duties of that committee are described fairly extensively in Article II, paragraph 5, and one of them (d iii) is: "the export outside the territories of the Contracting Parties of equipment or materials developed, produced or processed under the collaboration described in Article I of this Agreement". This certainly includes the export of depleted uranium to Russia. And as a member of that Commission, the Netherlands (like Great Britain and Germany) has a veto over the entire doings of Urenco, because decisions are taken unanimously.

5.5.3 Protest against dumping nuclear waste

From the moment it was announced in October (2019) that depleted UF6 was being transported from Gronau to Siberia, the protest was huge. Especially in Germany, but also in Russia and even in the Netherlands. During the last transport in 2019, which departed from Gronau on December 9, there were demonstrations in 10 places along the route in Germany and also in the Netherlands in Hengelo and Amsterdam,[37] while in the municipal councils of Enschede, Amsterdam and Venlo critical questions were asked. From the port of Amsterdam the radioactive waste goes by ship to St. Petersburg in Russia and then by train to Novouralsk. During transport in December, demonstrations were also held in various places along the route in Russia. A petition against the import of radioactive waste signed by 70,000 Russians[38] was offered to the German Environment Ministry on January 23, 2020.[39]

According to environmental groups, this is for Urenco a cheap way to get rid of its waste or it is at least a convenient way to move large quantities of depleted uranium and to transfer the responsibility for storage somewhere else. And the 'management' of waste streams is clearly the motive for Urenco UK, the contract is used "to limit the quantities or tail stocks stored at Capenhurst".[40] This practice has nothing to do with noble matters such as re-enrichment or recycling, but is simple meant to export (or move) radioactive waste. And that is just a matter of money and not wanting to take responsibility for the radioactive waste.

5.6 Final storage

No matter what happens to the depleted uranium and wherever it is stored, eventually there will come a time when the large quantities must be permanently stored in a final storage facility. However, a facility for long-term (permanent) storage of depleted uranium does not exist anywhere. In the Netherlands a final storage facility is not expected until 2120, in Germany and Great Britain somewhere in the middle of this century; Russia is developing plans for final storage, but the conversion from UF6 to U3O8 is expected to last until 2080.[41] Such final storage offers unprecedented challenges, also for depleted uranium, and not just because of the huge volume. Depleted uranium has the unusual property of becoming more dangerous over time: after 50,000 years the radioactivity starts to increase, it reaches its maximum activity after about two million years and remains at that level for a billion years.[42] This radioactive waste alone is therefore a major challenge for the future.

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CHAPTER 6: HALEU, TRITIUM AND THE BOMB

Uranium enrichment is one of the ways to the atomic bomb. It is not for nothing that the non-proliferation policy is aimed at having as few countries as possible possess enrichment technology. Therefor the International Atomic Energy Agency has set up a "fuel bank", where countries can get their enriched uranium so that future enrichment can be limited to a few countries. And so it becomes increasingly clear that nuclear energy is a technology that has military aspects. And uranium enrichment too.

6.1 Tritium and American nuclear weapons

In May 2017, it is announced that Urenco has concluded a contract for the supply of low enriched uranium (LEU) to the American TVA. TVA is the owner of nuclear power plants that are commissioned by the US Department of Defense to produce – with specially developed fuel rods – tritium for the US nuclear weapons program. Although uncertainty remains as to whether Urenco enriched uranium is actually used in those nuclear power stations, the fact is that Urenco has agreed to supply LEU even if it is used to produce tritium for nuclear weapons. In a 2014 report from the US GAO "Interagency Review Needed to Update U.S. Position on Enriched Uranium That Can Be Used for Tritium Production", it is stated that the Urenco Joint Commission agreed to deliver enriched uranium, while the possible production of tritium in those reactors was known.[1]

Radioactive tritium arises from nuclear fission and has a half-life of approximately 12 years. The American nuclear weapons program is in need of tritium because the tritium in the nuclear weapons must be regularly replaced. The problem for the USA at the moment is that it (since 2013 and for the first time since WWII) no longer has its own uranium enrichment facility and is therefore forced to purchase enriched uranium from foreign producers.

The US does assess tritium production in civilian reactors as military production and therefore the US-policy for the production of tritium is based on "Unobligated LEU". This means that uranium used for tritium production cannot be covered by treaties that limit its use to peaceful use. That has been the policy of the American government for decades, precisely to separate the peaceful and military use as clearly as possible. That is the problem for the US right now: America no longer has its own uranium enrichment capacity, and depends on the commercial market for LEU. And commercial LEU from outside the US – and also LEU enriched at the Urenco plant in the US itself – always falls under agreements with obligations, such as those in the Washington Treaty. For the US government it is crystal clear: the production of tritium for nuclear weapons in civil nuclear power plants is military.

According to the American General Accounting Office, Urenco and the owner-states (the Netherlands, United Kingdom and Germany) see that very differently. They think that the low enriched uranium is mainly used for the production of electricity and that the tritium is only a "by-product". Literally: "According to URENCO's legal memorandum, it was further discussed that URENCO LES's LEU will be used by TVA principally to produce electricity and that, if used in TVA's tritium producing reactor, the resulting tritium produced in that reactor is a by-product material and not a special nuclear material."

That is highly debatable when it comes to contractually mandatory delivery with specially developed fuel rods.

In the meantime, it seems that the US government has been able to push back the need to use uranium enriched by Urenco considerably, because a stock of enriched uranium has been found somewhere. But the fact remains that the Urenco countries did not mind cooperating with the American nuclear weapons program.

Another possibility for the US to no longer be dependent on "obligated" uranium is to set up its own enrichment industry (which has once again been initiated) or to buy Urenco in its entirety (see Chapter 3.5: Privatization). And that is now being thought out loud.[2]

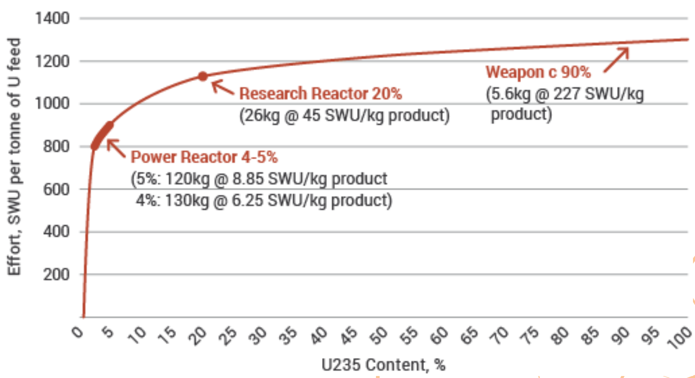
6.2 HALEU and military applications

From the foregoing it seems clear that Urenco is not so keen on the widely professed separation between civilian and military use of nuclear energy.

In February 2019, Urenco announces that it will enrich uranium in its American enrichment plant to 19.75%. That is the maximum enrichment rate to fall into the low-enriched uranium category. The Dutch site in Almelo has a permit to enrich uranium up to 6%. Nuclear power stations use uranium with a percentage of approximately 3.5–5% fissile uranium-235. According to Urenco[3], the higher enrichment rate of 19.75% is necessary for use in research reactors, but also for the development of new reactor types and for the production of medical isotopes. Because this is only half the story, Urenco's intention raises a lot of eyebrows.

The other half of the story is military: according to members of the Science, Space and Technology subcommittees of the US congress, the HALEU (High Assay Low Enriched Uranium) program is "a program that will ultimately be greater benefit to defense applications".[4]

Uranium Enrichment and Uses



And one wonders why in October 2019 the Department of Energy and not the Department of Defense made $115 million available to the Centrus company to set up a test plant to produce HALEU. Because Centrus is owned and operated by a US entity and will use enrichment centrifuge technology developed in the US, the Department of Energy emphasizes that it is the only company that can enrich uranium for use in the US military sector. As explained above, US policy prohibits the military use of uranium that falls under international non-proliferation treaties: “obligated uranium”. The policy is that for military applications only uranium is used that is enriched in American factories with American technology, and therefore not covered by international treaties: “unobligated uranium”.

But Urenco also wants to get involved in the production of HALEU and has no objection whatsoever to the military use of uranium enriched by them. So it appears again. That is because the new civilian reactor types that would require the HALEU are certainly not available in the “time-frame” for HALEU production in the Centrus program; the only (civil) advanced reactor type that fits into that timetable, the NuScale design, does not need HALEU![5]

The US Department of Defense does need HALEU because it wants nuclear mini-reactors for remote military bases and for example reactors in military submarines and aircraft carriers. Up to 19.75% (20% popularly) enriched uranium falls under the category of low enriched uranium, above 20% it is called highly enriched and from about 85% it is called “weapons-grade”. The latter is somewhat misleading, because even lower enriched uranium – in theory even 20% or less – can be used for a nuclear weapons, you only need more of it.

A higher enrichment rate is therefore controversial: the danger of further enrichment up to a percentage that is usable in nuclear weapons is high. The number of SWU is very large for the first 4–5 percent enrichment, but is then virtually nil for higher enrichment. In other words, it is fairly effortless and quickly realizable to get from 20% to 80% enriched uranium. (See image “Uranium Enrichment and Uses”)

The Urenco enrichment plant in Almelo may enrich uranium to 10% U-235, but must request permission from the nuclear regulator if the enrichment rate exceeds 6%. By way of comparison, according to the (now canceled) nuclear agreement,[6] Iran can enrich uranium to only 3.67% and must ‘dilute’ HALEU stocks to that percentage.

Unlike the American congress, the Netherlands believes that the military application of HALEU is not an obstacle on the basis of the Treaty of Almelo (jointly) responsible for Urenco. *Physics Today*: “The Urenco partner states have said their 1995 agreement with the US does not prohibit the company from providing HALEU for military reactors or LEU for tritium production”.

It remains remarkable that Urenco thinks it is fine to be part of the American nuclear weapons program, while the US itself really does wants to uphold the separation between ‘civil’ and ‘military’ use of nuclear technology and materials. And even more the Dutch government agrees with Urenco’s military ambitions, because otherwise the Netherlands would have used its veto in the Joint Committee. Or is this being pre-sorted by the respective authorities for the suggested upcoming sale of Urenco to the US, so that this nuclear weapon state will be able to use enriched uranium for military purposes without any problems?

Perpetual secrecy

Following the decision of the Joint Committee, and the position of the Dutch cabinet represented thereon, on the supply of tritium, the Laka Foundation tried to disclose documents from the Joint Committee. However, the Court of Amsterdam judges that the international Treaty of Almelo, which regulates secrecy, is more important than any national legislation.[1] Where secret documents are normally evaluated after a few years as to whether secrecy is still useful, such as minutes of the Council of Ministers on Srebrenica, it follows from the judgment of the court that all documents from the Netherlands concerning the supervision of Urenco since the establishment of the Treaty of Almelo in 1970 will remain secret into eternity, with no prospect of public access.

1 Laka Foundation, May 3, 2019: https://www.laka.org/nieuws/2019/rechtbank-amsterdam- gemengde-commissie-mag-alles-over-urenco-geheim-houden-10628

6.3 Nuclear energy necessity for nuclear weapons program

The separation between military and civilian use of nuclear energy has always been artificial. For example, it is quite possible to make nuclear weapons from plutonium from nuclear reactor fuel[7] and uranium enrichment has undeniable military potential.

In recent years, something else has become clear: the official nuclear weapon states (US, UK, Russia, France and China – together accounting for more than 60% of the number of nuclear power reactors, 255 out of 415) have a major interest in maintaining the civil nuclear program. And there is less and less disguised talk about it.

Without a "robust" civilian nuclear industry and associated nuclear infrastructure, nuclear weapons programs would not be sustainable due to high costs, risks and the need for trained personnel.

- In all nuclear-weapon states, the military apparatus uses the civilian nuclear industry through hidden subsidies for human resources, research funds and investment in dual-use nuclear infrastructure.
- The modernization of nuclear arsenals in Nuclear Weapon States encourages the development of new small modular reactors (Small Modular Reactors)
- Although reportedly intended for civilian use, small reactors are mainly used for military purposes, in particular for the propulsion of nuclear submarines, which have become the most important part of the nuclear weapons doctrines of the major nuclear powers.
- If submarine nuclear propulsion units can be used with HALEU (enrichment level of 5–20%) instead of HEU (enrichment level of more than 20%), the civilian nuclear industry can produce relatively inexpensive and uncomplicated nuclear fuel for nuclear submarines.

U-battery

Urenco has been developing a mini-reactor since 2008: the U-battery, with the U from Urenco. The project was started in collaboration with the Technical University in Delft (NL) and the Dalton Nuclear Institute of the University of Manchester (UK). Urenco has entered into a partnership with a number of companies in the U-Battery consortium.[1]

The U-battery uses so-called Triso fuel, which consists of higher-enriched low-enriched uranium (or HALEU). It is therefore remarkable that uranium enricher Urenco is designing a reactor for which enriched uranium is necessary that it cannot itself enrich. But that one day will undoubtedly be the main reason for the call to be allowed to enrich higher. In this way you create foolish facts that you can put pressure on politicians with.

Mini reactors (SMRs: Small Modular Reactors) are the new hope of the nuclear industry. According to the U-Battery[2] prospectus there is a lot of interest in it; especially in Canada, where it would be used to supply power to remote areas where it is not profitable to draw power cables. Power in remote areas is the most important selling point, but research shows that they are mainly developed to extract oil, tar sands and gas from hard-to-reach locations. The Akademik Lomonosov, the Russian floating nuclear reactor, is intended, for example, to be able to explore and exploit fossil fuels at the North Pole. The U-Battery that Urenco is developing in collaboration with Canada could allow the extraction of tar sands in inhospitable areas. And there are more examples. It therefore appears that the mini-nuclear reactors currently being developed are only going to aggravate the climate crisis.[3]

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2 https://www.u-battery.com/_/uploads/U-Battery_Prospectus_2019.pdf
3 https://reneweconomy.com.au/the-advanced-nuclear-power-sector-is-fuelling-climate-change-and-wmds-40205/

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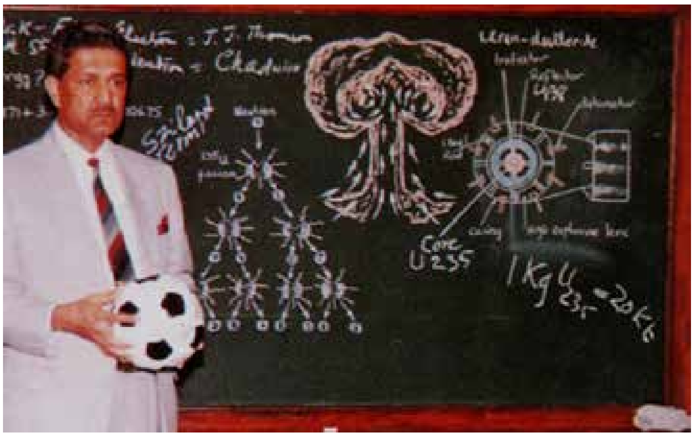
CHAPTER 7: A.Q. KHAN AND OTHER SCANDALS

The Urenco plant at Almelo has been – certainly for the first 15 years – at the center of attention: it seemed as if one scandal had not yet finished before the next appeared. In Germany that was much less during that period, but the discussion has been flaring up considerably in the past 10 years. In Great Britain it is relatively quiet around Urenco Capenhurst, but that was also different in the past. The fact that there are fewer scandals does not mean that everything is now much better.



A.Q. Khan lecturing.

7.1 Theft of enrichment technology

Because enrichment technology is a proliferation-sensitive technology that gives countries the opportunity to develop nuclear weapons, the policy is aimed at preventing the spread of that technology. In the past this has not been possible and with digitization it has become a lot more difficult – a cubic meter of documents fits on a simple USB stick.

7.1.1 Abdul Qadeer Khan[1]

After the broadcast on German channel ZDF on 29 March 1979, of a documentary about Dutch enrichment technology that had ended up in Pakistan through espionage, Dutch politics also became interested and parliamentary questions were asked. On May 3, the Minister of Economic Affairs downplayed the affair: “It is not correct that knowledge about enrichment technology was obtained directly from Urenco Nederland by Pakistan.”

Through a broadcast by Walter Cronkite on the American news channel CBS, the spy also got a name: Abdul Qadeer Khan.[2] In February 1980, the Dutch government had to come back to previous statements, it is “likely that Pakistan through Khan is in possession of sensitive knowledge in the field of enrichment technology” and that Pakistan has “gained considerable time” in setting up a trial enrichment plant.

It gradually became clear to everyone that A.Q. Khan stole secret blueprints of modern ultra-centrifuges at the Urenco plant in Almelo and took them to Pakistan. Although the Netherlands should have been aware of the theft for years, the government remained in the denial phase for a long time.

7.1.1.1 Concealing espionage from partners

It was not until 16 June 1979 that the Netherlands first officially notified Britain and West Germany of Khan and the theft of classified information. That happened in the secret Joint Committee only after almost every newspaper reported about the theft. The Urenco partners were certainly not happy with the late notification. For example, Norman Lamont, UK undersecretary of state for energy, could not hide his irritation. After a question from Labor Member Tam Dalyell, during a debate in the UK Parliament on 18 December 1979, he replied: “The Hon. Member asked, quite rightly, “Why was the United Kingdom not informed?” It is a question that we have been asking the Netherlands authorities. To date, we have received no satisfactory explanation.”[3]

According to Khan’s’ colleague and whistleblower Dutchman Frits Veerman, he – Veerman – had informed colleagues (in personal conversations and sometimes covertly) from 1974 onwards of his suspicions after seeing secret blueprints of centrifuges at Khan’s home.[4] But if that was not enough, everything should have been clear in December 1975 when Khan did not return to the Netherlands from his vacation in Pakistan.

From the very beginning of the Urenco cooperation, the prevention of proliferation was mentioned as one of the main arguments and there are “rules [are] designed to ensure that access to sensitive information is tightly controlled”.[5] But even in the regular meetings of Urenco’s Joint Commission, the Netherlands apparently did not mention that secrets had been leaked to Pakistan. It was not until 16 June 1979 that Britain and West Germany were informed of this important non-proliferation breach by a Dutch report in the Joint Committee.

According to the British state secretary in the December 1979 debate, people from “fourth countries” should be able to access confidential information “only with the express agreement of the joint committee.” And the British minister left no doubt that such permission was not requested by the Netherlands. “No such clearance was sought in the case of Dr. Khan, nor was his departure to Pakistan notified to the joint committee in 1975.” And the minister went on to state that “Nor, as required by the Treaty of Almelo, was the apparent breach of security reported to the joint committee until long after it occurred.”

That even the Joint Committee was not informed does makes clear the intention of the Netherlands. The government wanted to keep the whole affair secret at all costs and not only to the general public, but also to the governments of the partner countries. Because everything that is discussed in the Joint Commission is secret and remains secret anyway; the parliament has no possibility to steer the policy and has no control over it. A serious democratic deficit that has not been corrected up to now.[6]

The question is to what extent the concealment of the Khan affair for the Urenco partners has made it possible that British and West German companies could continue to supply Pakistan. For example, some 20 high-frequency inverters were ordered in December 1977 by Pakistan from the British company Emerson Industrial Control and were shipped in August 1978. The inverters have to control the high-speed rotations of the centrifuges.

Employees of Emerson assumed the inverters would be used for uranium enrichment, but thought that "[T] he Pakistani would never know how to operate such sophisticated equipment, and that the inverters would all sit in their packing cases until they rusted away." That turned out not to be the case. Unrest arose over a larger follow-up order and, probably after a tip from an employee of the company, Labour asked for on inquiry in British parliament; eventually an investigation followed, exports to Pakistan were frozen and export conditions were tightened.[7]

The refusal of the Netherlands to inform the Urenco partners as soon as possible about Khan's nuclear espionage was the second time the Netherlands had kept important matters secret from its partners: previously in 1969, during the negotiations for the establishment of Urenco, the Netherlands had kept secret from German and British partners that a number of centrifuges had imploded.[8]

Many years later, in 2005, in a broadcast of the Dutch radio program Argos, Ruud Lubbers, in 1975 Minister of Economic Affairs, revealed that the Netherlands had "let go" Khan twice after pressure from the American intelligence agency CIA.[9] The same CIA, which later described Khan as "at least as dangerous as Osama bin Laden".[10]

7.1.1.2 The Khan network

After graduating in metal science from Delft university, Khan became an employee of the Dutch company FDO in 1972. FDO, based in Amsterdam, did research for Urenco on certain parts of centrifuge technology. Khan also worked in Almelo, where he copied the then very advanced Dutch M4 centrifuge-technology.

In 1975, Khan did not return to the Netherlands from a holiday in Pakistan. After he was initially sentenced in absentia to four years in prison by the Amsterdam District Court in 1983, he was acquitted on appeal in March 1985 for a formal error: it was unclear whether he had received the summons.

In January 2009, a Dutch study friend of Khan, Henk Slebos, was sentenced to 18 months in prison for the illegal export of proliferation-sensitive technology to Pakistan.[11] Slebos is just one of the many "associates" of Khan: in *Deception*, a list of "Principle Characters" in the Khan network has been included as an attachment, including a list of 11 European contacts, the majority of whom have been convicted of smuggling.[12] From the beginning of this century it became increasingly clear that Khan was the hub in a network that sold nuclear enrichment technology to other countries. The centrifuges found in Iran and Libya where based on the 4M copied by Khan and therefore have a "Dutch fingerprint."

Khan, meanwhile, became a national hero in Pakistan; the "Father of the Atomic Bomb". In 2004 he admitted selling nuclear technology to North Korea, Libya and Iran between 1986 and 1993. In a revealing article by proliferation experts Albright and Hinderstein[13] they mention that Khan offered his 'assistance' to Egypt, Syria, Iraq, Saudi Arabia and Al Qaida in addition to the three countries mentioned above. Furthermore, they argue, the fact that Khan visited 18 countries between 1997 and 2003 has fueled further speculation about his potential clientele.

In addition to the nuclear arms race between India and Pakistan and the nuclear weapons program of North Korea, Iran's nuclear program, which in recent years has regularly led to tensions and armed actions, can also be traced back to Urenco Almelo. It is almost impossible to overestimate the importance of the lax attitude of both Urenco and the successive Dutch governments in enabling Khan to take off with the crown jewels. And the consequences of the technology stolen from Urenco in Almelo in the early 1970s have largely determined the global proliferation agenda of recent decades. Up to the present day.

7.1.2 Urenco technology in Iraq

Khan is not the only one who stole Urenco technology, others did so too, but undoubtedly with less impact. Between 1985 and 1990, secret blueprints with specifications of the then most modern ultracentrifuge, the TC11, were stolen by former employees of the company MAN. The company was at that time the main shareholder of the German Urenco partner Uranit.[14] The highly secret blueprints were copied at Uranit's office by Stemmler and Schaab and sold to Iraq.[15] The International Atomic Energy Agency discovered the advanced carbon-fiber reinforced TC11 ultracentrifuges in Iraq, after a top Iraqi official with some sensitive documents had fled to Jordan.[16]

7.2 Enriched uranium to Brazil[17]

In June 1975 Urenco partner West Germany signed a huge contract with Brazil for the supply of a complete nuclear energy cycle consisting of enrichment, nuclear power stations and reprocessing plants. Brazil had not signed the Non-Proliferation Treaty (which is intended to prevent the proliferation of nuclear weapons) and was also a military dictatorship. At the same time, Germany sold nuclear technology to arch-enemy Argentina. The regime in Brazil was not secretive about its nuclear intentions: it had a nuclear weapons program, but that nuclear weapons would be developed for "peaceful purposes."

In March 1976, the Netherlands agreed in the Urenco Joint Commission to supply enriched uranium to Brazil. This contract made it necessary to considerably expand the enrichment capacity of the plant in Almelo. Brazil is Urenco's first major export customer. The discussion within the Social Democrats led Cabinet Den Uyl – where the smallest coalition partner PPR is threatening with a cabinet crisis – focuses on Brazil's nuclear safeguards.

But the German and British partners are not in favor of a revision of the already-agreed safeguards by the International Atomic Energy Agency (IAEA) and Brazil also refuses to cooperate on strict security conditions which are perceived discriminatory. What follows are a few years of ambiguity, blackmail and mystery. For example, both West Germany and the United Kingdom threaten not to renew the Treaty of Almelo in 1981 (a possibility laid down in the Treaty) and West Germany makes it clear that if a (positive) decision about expansion of the Almelo plant is not made rapidly, the Germans are forced to build an enrichment factory on their own territory. At the end of 1977 the new Christian Democrats-Liberals cabinet agreed to the expansion of the Urenco plant in Almelo and thus to the supply of enriched uranium to Brazil.

The largest anti-nuclear energy demonstration in Dutch history takes place in March 1978. With the central slogan “No expansion of UCN” (the name under which Urenco Almelo is known in that period) around 45,000 to 50,000 people demonstrate in Almelo, especially against the supply of enriched uranium to the military dictatorship of Brazil. Out of disappointment that the massive opposition did not lead to concrete results, the first direct actions against Urenco took place later that year by BAN: Break the Nuclear Chain Netherlands.

A few months later, at the end of June 1978, the Dutch Parliament approved the supply of enriched uranium to Brazil. Urenco Almelo had already started work on expansion in May. In December 1978, the government also agreed to the construction of the Urenco plant in Gronau, Germany.

In April 1981 it was announced that not Almelo but Capenhurst would enrich the uranium for Brazil staring in the beginning of 1982.[18] But due to financial problems and the great delay in the Brazilian nuclear program the contract was not nearly as large as originally discussed.[19] In 1985 the military dictatorship came to an end but Brazil did not sign the Non-Proliferation Treaty until September 1998. A new enrichment contract was being discussed at the end of the 1980s and Brazil is still one of the Urenco customers to this day.

Germany ultimately sold a nuclear reactor, but not an enrichment plant or a reprocessing plant.

7.3 Enrichment of uranium from occupied Namibia

At the start of commercial enrichment in the factories in Almelo and Capenhurst (Autumn 1977) it became clear that in Capenhurst and Almelo uranium from Namibia is being enriched. With this, Urenco violates Decree Nr. 1 of the Namibia Council of the United Nations. That decree prohibits the exploitation, trade, transport, processing and use of raw materials from this country which is occupied by South Africa.

The Dutch involvement in uranium trading from Namibia is of an indirect nature; The Netherlands itself does not purchase uranium from Namibia or South Africa. Dutch involvement is crucial, however, because the Netherlands is an equal partner in Urenco and the enrichment of Namibian uranium is taking place at the enrichment plants in Capenhurst and Almelo. The contractual involvement of Urenco Almelo raises an interesting point. While the British and West Germans do not recognize the legal authority of the UN Council for Namibia, the Dutch government does. It recognizes both the 1971 ruling of the International Court of Justice that the South African government in Namibia is illegal and the legal basis of Decree No. 1 of 1974 by the UN Council for Namibia.[20]

7.3.1 Namibian uranium and the UN process[21]

In 1978, the Dutch Anti-Apartheid movement brought the matter to the attention and reproached the Dutch government for taking no action whatsoever to give practical substance to the position it adopted; not via transport restrictions, not via (the Joint Committee of) Urenco and not via Euratom (which also has the right to determine the “geographical origin” of the goods to be supplied).

At a UN hearing on the case, the Netherlands stated that it did not see it as its task to “implement” the decree. The Netherlands defended itself with the statement that it cannot know where the uranium originated from: Urenco is not the owner of the uranium and only enriches it. The UN then calls this “healing”, because of course it is possible to make demands on customers about the origin of uranium. In May 1985, the UN announced a trial against Urenco and the Dutch state, which it is hoped can still start “before the end of the year”.

On 14 July 1987, the summons of the UN Council for Namibia is finally published and on September 1 that year, during the first session, the trial is immediately adjourned to December 1 to give the defendants time to prepare their defense. On December 1 it is subsequently further adjourned to 3 May 1988. The essence of the (written) defense of the Dutch State is that it cannot be demonstrated that the uranium at Urenco Almelo originates from Namibia and that therefore the Netherlands cannot be accused of unlawful processing raw materials from occupied Namibia. At the hearing on 6 June 1989, the Namibia Council’s reply is that the Dutch State can derive from agreements where the uranium comes from and that a bank that receives stolen money cannot defend itself with the argument that the money doesn’t show it has been stolen.

But that is it: at the beginning of 1990, South Africa withdrew from Namibia, which became independent on 21 March 1990. The trial is stopped without judgment.

7.3.2 Namibian uranium in Great Britain

The contract for the supply of Namibian uranium to Great Britain is concluded with UKAEA[22] in 1968 (i.e. before the establishment of Urenco) and is taken over by this Urenco partner after the establishment of BNFL[23] in 1971. Most of the uranium from the Namibian Rössing mine goes to Great Britain, but also to a number of other Urenco customers.

The Labor Party promised to cancel the 1968 contract, but when the party after winning the 1974 general elections came back to that promise, protest increased sharply.[24] Between 1977 and 1985 half of the uranium for the British civilian nuclear program came from the Rössing mine in Namibia. In addition, all the uranium for the British military program came from Namibia and South Africa.[25] A campaign was being set up by Anti-Apartheid organizations, students, environmental movements together with trade unions to stop the import of uranium from Namibia. This collaboration CANUC (the Campaign Against the Namibian Uranium Contracts) ensured a constant flow of information and the campaign focused to a large extent on the processing of the uranium in Capenhurst.

In addition to the boycotts of workers on ships carrying uranium from Namibia in the port of Liverpool, one of the highlights of the protest is the National Day of Action on 14 March 1981, when demonstrations are taking place on 30 locations, including Capenhurst.[26]

7.4 And today's scandals?

It seems as if scandals are something of "the past"; as if there are no more scandalous things happening around Urenco. But scandals do not occur automatically. If not many people find something that is outrageous, there will be no public scandal. And that has been the case in the Netherlands (and the UK) for a long time.

In Germany it is different. This is where scandal after scandal concerning Urenco Gronau has arisen in the past couple of years. There were numerous topics about which the media reported critically, triggering discussion in parliament; in short, scandals. About the involvement in the American nuclear weapons program, the supply of enriched uranium for the fuel for the 'crack reactors' in Tihange and Doel and even about the parliamentary debate on the Ausstieg van Lingen and Gronau where strange things happened with official documents and speakers.[27] But especially the scandal of dumping depleted uranium in Russia.

What became a scandal nowhere is the contract for the supply of enriched uranium to the United Arab Emirates.[28] And that is strange. A dictatorship, a country where homosexuality is punishable, where a non-Jewish declaration is requested, in a region where nuclear technology and nuclear ambitions raise a lot of eyebrows.

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22 The United Kingdom Atomic Energy Authority is the state organization that is responsible for both the civilian and military nuclear programs at that time

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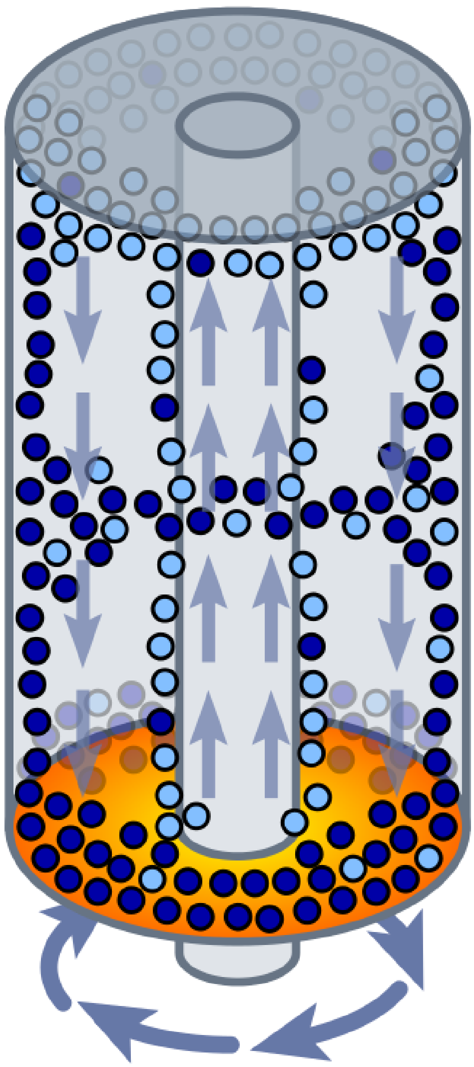
ANNEX I:
ENRICHMENT: FEED, PRODUCT AND TAILS

Enrichment means increasing the concentration of a particular isotope of interest in an element. Although not limited to uranium, the term is usually used to enrich the U-235 isotope in uranium.Natural uranium consists for the most part of the isotope U-238, while the fissile isotope U-235 makes up only 0.72% of all uranium atoms (or 0.711% of the mass). To maintain a nuclear chain reaction, the fissionable U-235 percentage must be increased to approximately 3–5%. The process of increasing the U-235 fraction in uranium is called uranium enrichment.

Commercial enrichment technology is now almost exclusively based on gas centrifuges. In these centrifuges, a gaseous uranium compound (uranium hexafluoride – UF6 – which is also gaseous at relatively low temperatures) is exposed to strong centrifugal forces, separating the lighter (U-235) from the heavier isotopes (U-238). Because the enrichment obtained in a single centrifuge is not sufficient, many centrifuges are linked to each other in so-called cascades. These cascades are again used in parallel formations to achieve the desired degree of enrichment.

Illustration of the gas diffusion enrichment process.



The labor required for enrichment is measured in SWU: Separative Work Units. 1 SWU is equivalent to 1 kg of separation labor. Capacity of an enrichment installation is stated in tonnes (1000 kg) of SWU per year (tSWU / y). Enriching from 0.7 to 4–5% U-235 requires more SWU than from 5% to 100%.

A nuclear power plant with a capacity of 1,000 MW requires approximately 25 tonnes of 3.5% enriched uranium annually. The production of this enriched uranium from natural uranium requires around 120 tSWU. An enrichment installation with a capacity of 1,000 tSWU / y can therefore enrich the uranium annually for around eight nuclear power plants.

Uranium with a U-235 content to be increased (“feed”) is loaded in centrifuges. Enrichment results in two streams: a stream with a percentage of U-235 higher than the natural 0.72% (enriched uranium or ‘product’) and a stream with a percentage of U-235 lower than 0.72% (depleted uranium or ‘tails’). The depleted uranium represents more than 85% of the mass output of the enrichment plant, in other words: the production of 1 kilo of enriched uranium yields – as a by-product or waste – more than 7 kilos of depleted uranium!

Theoretically, it is possible to extract even more fissionable uranium from the depleted uranium, which on average still contains 0.2-0.3% U-235. The usefulness of this “re-enrichment” depends on a number of economic factors: the price of “fresh” natural uranium, the price of a SWU and, nowadays, an excess of enrichment capacity (overcapacity). Re-enrichment is not effective to reduce the volume of depleted uranium, but can be used (and is used) to move those volumes: e.g. from Western Europe to Siberia (see Chapter 6: Export of depleted uranium to Russia).

ANNEX II: HISTORY OF URANIUM ENRICHMENT AND MARKET

In the beginning all uranium enrichment took place for the production of nuclear weapons. Within the Manhattan project, enrichment was one of the two routes to the atomic bomb: the other was obtaining plutonium by reprocessing. At the time, research into uranium enrichment was mainly based on ultracentrifuge technology to separate uranium isotopes, but after a number of centrifuges had exploded, they switched to gas diffusion technology in December 1943.[1]

1950s: military enrichment capacity

In the 1950s, the US expanded its enrichment capacity built during the Second World War with three enormous diffusion installations with a total capacity of 17,000 tSWU / y.[2] The British also built diffusion installations for their nuclear weapons programs and in 1953 opened a factory in Capenhurst with a small capacity (400 tSWU / y) .[3] Also the Soviet Union started a large military uranium enrichment program. Tenex was established in 1953 for the export of enriched uranium (initially exclusively to countries within the Soviet bloc).[4] China also started producing highly enriched uranium for the nuclear weapons program in two enrichment plants (Lanzhou and Heping) in the late 1950s, both through gas diffusion.[5]

When the various European Communities were set up in the mid-1950s, France proposed that the European Community started its own enrichment project: which would have to be within Euratom: the European Community's partnership and lobby organization for atomic energy. But the US responded to those plans with an offer that Europe "could not refuse": cheap, subsidized by the American government, uranium, enriched by the major American diffusion plants. By accepting the American offer, the discussion and implementation of enrichment technology in Western Europe was postponed considerably.[6] France in 1960 started its own national enrichment industry with the construction of the (military) enrichment plant in Pierrelatte, which began to produce in 1964.[7]

Breaking the US monopoly

From a virtual monopoly on uranium enrichment – outside the Soviet bloc – in the 1950s and 1960s, the US share of the world market fell during the 1970s to less than 60% at the end of 1982.[8] France was the first country to break the US monopoly and signed an agreement in March 1971 for the supply of enriched uranium with Russian Tenex.[9] In 1975 already 8.8% of enriched uranium in the Euro-9[10] came from the Soviet Union.[11] In the following 10 years, the position of the US as the dominant world supplier was quickly eroded for two reasons:[12]

– In the first place, the US was increasingly seen as an unreliable supplier of enriched uranium; because the order book was larger than the production capacity, no new orders were concluded between 1974 and 1978.

– Secondly, US policy to prevent even more countries from possessing nuclear weapons evolved to the Nuclear Non-Proliferation Act of 1978, imposing more restrictions on foreign buyers of enriched uranium.

These factors increased the interest of countries to develop their own enrichment facilities.

1970s: Multinational cooperation

The Urenco company was founded by the Federal Republic of Germany, the United Kingdom and the Netherlands in the early 1970s and started building their own enrichment capacity. The first commercial delivery of enriched uranium by Urenco took place in September 1975. Although these deliveries were relatively small and came from pilot plants, Urenco did gain in importance.[13] In 1977 the first commercial factories were officially put into operation: on 15 September in Capenhurst and on 25 October in Almelo,[14] while in August 1985 production started at the German Gronau plant.[15]

Eurodif was established by France in 1973 as a joint venture with four participating partners: Belgium, Italy, Spain and Sweden (in 1975 Iran would take over Sweden's 10% share). However, unlike Urenco, the partners did not have access to the technology, only – and only to a certain extent – to the product.[16] Eurodif opted for gas diffusion technology and in 1979 production started in Tricastin, France. Capacity quickly expanded to 10,800 tSWU / y in the mid-1980s, making Eurodif one of the world's largest producers of enriched uranium.[17]

Small number of producers

In 1976, only five countries had uranium enrichment facilities larger than a pilot plant. These were the five official nuclear weapon states: the US, the United Kingdom, France, Soviet Union and China. All their existing factories were initially built for military purposes. Of the five, only the US and Russia had sufficient capacity to also enrich for export.[18] That changed with the arrival of Urenco and Eurodif.

Years '10: end of US position and of diffusion technology

Currently, the situation is more or less the same as 50 years ago: a small number of producers dominate the enrichment market. But important changes have taken place with regard to those producers and the technology. Instead of being a market leader, the US actually no longer has its own enrichment capacity.

In 2013, the last diffusion enrichment plant (the Paducah Gas Diffusion Plant)[19] closed while the American Centrifuge Plant, which was intended to replace Paducah, suffered enormous delays and failed. The government stopped financing at the end of 2015.[20]

The Paducah plant.

Urenco opened a new enrichment plant in the US in 2010 in Eunice,[21] but it appears that the lack of an American enrichment capacity with American technology has serious consequences in some areas. There are attempts to rebuild the American enrichment industry. Last year, the Department of Energy (DoE) announced that it would make US $115 million available to the company Centrus.[22]

In June 2012, a year before the closure of the Paducah diffusion plant, the diffusion plant in Tricastin, France,[23] closed: after 70 years the curtains fell definitively to the application of gas diffusion technology for the enrichment of uranium.[24] The French state-owned nuclear company Aréva (now renamed Orano) proceeded with this closure when the capacity of the replacement centrifuge factory Georges Besse II reached 1,500 tSWU / y.[25]

Cost advantage of centrifuge technology

One of the main reasons for the rapid rise of centrifuge enrichment is the cost factor: and especially the high-power consumption of diffusion compared to centrifuge enrichment. The diffusion technology consumes around 2,500 kWh per SWU, while modern centrifuge plants only need around 50 kWh per SWU.[26]

An enrichment installation with a capacity of 1,000 tSWU / y can annually enrich the uranium for around eight nuclear power plants of 1000 Mwe to 3.5%.[27]

Enrichment (over) capacity, price SWU

Due to the continuing optimistic growth scenarios for nuclear energy, the enrichment market is in fact struggling with overcapacity. Due to less expansion of the planned enrichment capacity (and due to failed projects – especially in the US), overcapacity has decreased somewhat in the last decade. Urenco Almelo, for example, has had a permit for 6,200 tSWU / y since 2011, but the actual production capacity is 5,200 tSWU / y. And Urenco USA may expand to 10,000 tSWU / y, but remains stuck at 4,900 for the time being. The global enrichment capacity expected in 2013 for the year 2020 was still around 80,000 tSWU / y.[28]

Long-term global overcapacity has consequences for the price of enrichment, which is currently historically low.

SWU production (in tonnes of SWU per year):

Country/Company	1978	1998	2019
US (without Urenco)	27.300	19.400	-
Russia (Soviet Union)	20.000	20.000	23.600
France (Eurodif)	600	10.800	7.500
Urenco	400	3.900	18.600
China	400	800	7.100
Other			600
Total	48.700	55.800	57.400

* 1 Figures 1978 and 1998: https://www.wiseinternational.org/nuclear-monitor/499-500/uranium-enrichment-no-capacity-growth-20-years (France adjusted, Laka 2020)

* 2 SWU-mergence: Reawakening of the Enrichment Market, presentation by Jonathan Hinze, President UxC, LLC, on NEI IUFS, October 29, 2019

* 3 In a presentation also at the NEI IUFS, Kirk Schnoebelen, President Urenco USA, the capacity of Russia is estimated at 28,000 tSWU / y

In its latest Annual Report[29] Urenco writes about the low SWU price: "[C] urrent price levels would not support reinvestment in our enrichment facilities", although they foresee an increase in price. Also the Dutch government, as a shareholder of Urenco, is not at ease: "The global demand for enriched uranium and therefore the potential earning capacity for Urenco has fallen." [30]

Laser enrichment

For more than 40 years, laser enrichment has been called a promising technique and the next step in isotope separation. *Science News* wrote in the mid-1970s that "plants producing enriched uranium by laser could be in operation by the early 1980s."

Despite much research, especially from the Nuclear Weapon States, there appears to be little progress. But the promise remained; also according to Urenco. The Dutch paper *Twentsche Courant*, for example, reports in 1990[32] that it will be decided in 1993 in which Urenco country the Urenco trial laser enrichment plant will be built. Almelo is said to be a promising contender because Urenco commissioned 'experiments in this area' at the nearby University of Twente.

The US started research into Atomic Vapor Laser Isotope Separation (AVLIS) in the 1970s as a replacement for diffusion enrichment plants. Expectations were high: in *Science magazine*,[33] AVLIS was described as "a clear winner". But after more than $2 billion was spent on research and development, the AVLIS development was stopped.[34]

In 1996, the US purchased the rights to further develop the SILEX process and to use it commercially.[35] The SILEX process (Separation of Isotopes by Laser EXcitation) was developed in Australia in the 1990s. In 2006, a collaboration between SILEX and the American technology and electronics company General Electric came into existence, and a few years later the Canadian company Cameco (the largest uranium mining company in the world listed on the stock exchange) joined. Apart from technological developments, the economic outlook for new enrichment capacity remained (and remains) poor, so General Electric left the cooperation in early 2019.[36]

Forty years after the first commercial laser enrichment plants were planned, commercial laser enrichment still does not exist.

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