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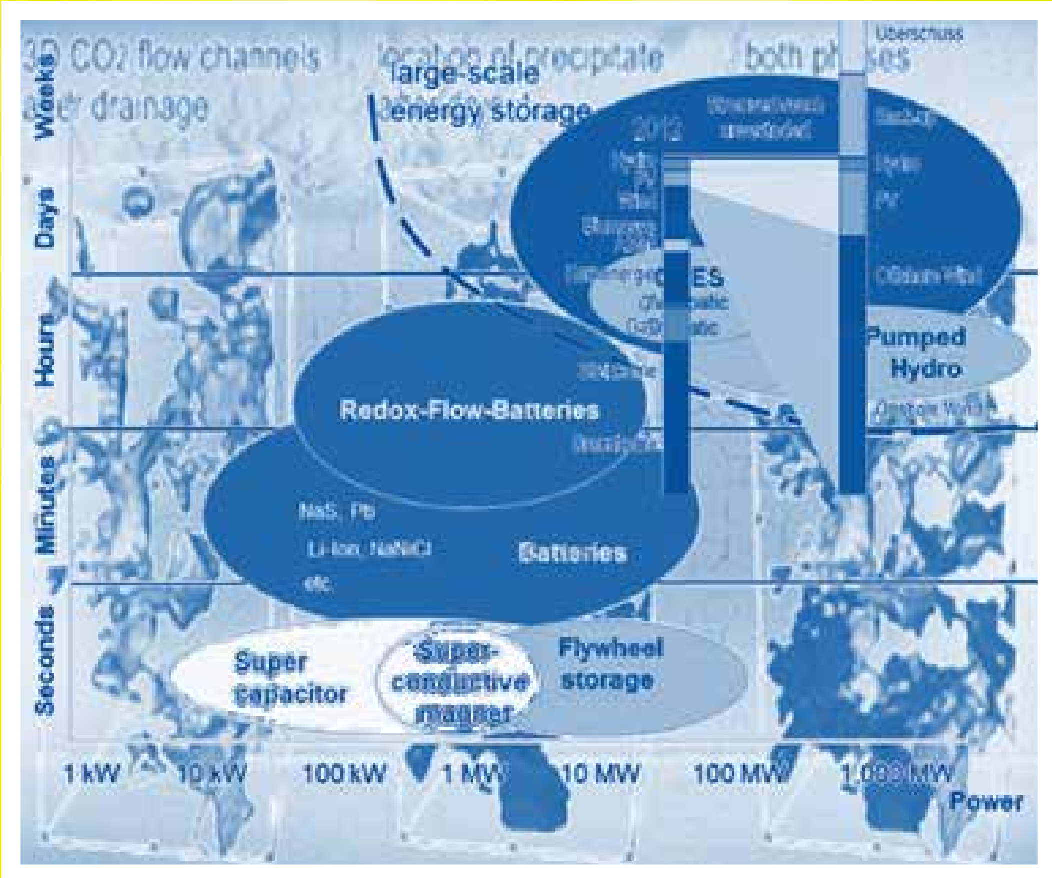

Energie

Erzeugung - Netze - Nutzung

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Nuclear Fission Energy: New Build, Operation, Fuel Cycle and Decommissioning in the International Perspective

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Abstract

Over 60 nuclear power reactors are in construction today and over 400 are connected to the grid. The presentation will show where. A nuclear new build project involves a team of several thousand people. Some pictures from ongoing new build projects will illustrate this.

Using concrete examples from the AREVA group, the nuclear fuel cycle from uranium mines in Niger, Kazakhstan or Canada to chemical conversion, enrichment and fuel manufacturing will be explained. Also the recycling of used fuel and the fabrication of MOX fuel is addressed.

Introduction

With demand for energy growing, oil and gas prices rising in the long term and the fight against climate change heating up, the development of clean energy that does not emit greenhouse gases is an absolute priority. The nuclear industry is committed to meeting the energy challenges of the coming years by producing carbon-free energy.

The French AREVA Group with its 44,000 employees (April 2015) worldwide contributes to this goal by providing high added-value products and services to support the operation of the global nuclear fleet. The company is present throughout the entire nuclear cycle, from uranium mining to used fuel recycling, including nuclear reactor design and operating services (Fig. 1). In detail this comprises the following activities:

- Uranium exploration, mining and concentration
- Uranium conversion and enrichment
- Nuclear fuel design and fabrication
- Nuclear reactor design and construction
- Products and services to maintain, upgrade and extend the operating period of existing power plants
- Used nuclear fuel recycling
- Project management and support for work in a radioactive environment
- Dismantling and redevelopment of nuclear sites
- Nuclear materials logistics, storage and disposal

The German headquarters of AREVA GmbH are located in Erlangen. Currently comprising around 3,400 employees, Erlangen is the company's largest engineering site. The main focus of activity in Erlangen is, on the one hand, the maintenance and modernization of power plants both in Germany and abroad. On the other hand, employees are involved in international construction projects in France, Finland and China. At the research facilities in Erlangen, the company is able to make use of institutions that are unique in the world, such as the primary circuit testing facility PKL. The OECD recently extended its funding of a large international project here by several years, which is working on simulations for safety research with regard to nuclear power plants.

In Erlangen, the company additionally operates a modern test field for the digital instrumentation and control system of nuclear power plants. The radiochemical laboratory is also unique and undertakes assignments for worldwide markets. As well as this, there are facilities for vibration and materials testing.

The fuel supply business division is also represented at the Erlangen site. Alongside fuel assembly testing stations, the fuel laboratory is also based in Erlangen. Here, new developments are produced in small series production and tested, for example assembly structure grids.

Fig. 1: The entire nuclear cycle, from uranium mining to used fuel recycling, including nuclear reactor design and operating services.

Uranium Mining

Mining activities are the first link in the nuclear fuel cycle and in the integrated model of the AREVA Group which was one of the top producers worldwide in 2014, producing 8,959 metric tons of uranium[1]. The company has a diverse assets and resources portfolio, which constitutes an important security factor for utilities seeking long-term guarantees with regard to uranium supplies. Mining employees are present on five continents. There are uranium production sites in three countries: Canada, Niger and Kazakhstan.

Natural uranium is a metal that does not occur in its native state. It contains two main isotopes: 238U (non-fissile) making up 99% and 235U (fissile) making up 0.7%. In nature, it exists only as an ore – an ore that must be extracted and processed to obtain uranium oxide (U_3O_8).

[1] Source: AREVA's financially consolidated share 2014

There are different techniques for the extraction of uranium ore:

- Open-pit mining for shallow deposits: The rock covering the ore is removed and the ore is dug out with mechanical shovels. It is then crushed and treated with chemicals to extract the uranium.
- Underground mining for deeper deposits: Galleries are dug and stabilized to reach and extract the ore, which is then crushed and processed.
- In situ recovery: This more recent technique is used to mine low-grade deposits. Instead of digging a pit or underground galleries, wells are drilled down to the orebody, and the ore is dissolved with a chemical solution. The solution is then pumped back to the surface and processed to extract the uranium.

At all mining sites, there are plants on site to extract and concentrate uranium. Often the uranium content of the ore is only a few kilos per ton. To extract the uranium, Chemical solutions are used suited to the specific characteristics of each ore. In most cases, these consist of an acid (e.g., sulfuric acid). With this process, 90% of the uranium in the ore can be recovered. The uranium is then purified and separated out of the solution by precipitation using sodium carbonate, magnesium oxide or another chemical. After washing and filtering, a paste consisting of 75% uranium metal remains. This material, more commonly known as "yellow cake", is used for the fabrication of fuel for nuclear power plants (Fig. 2).

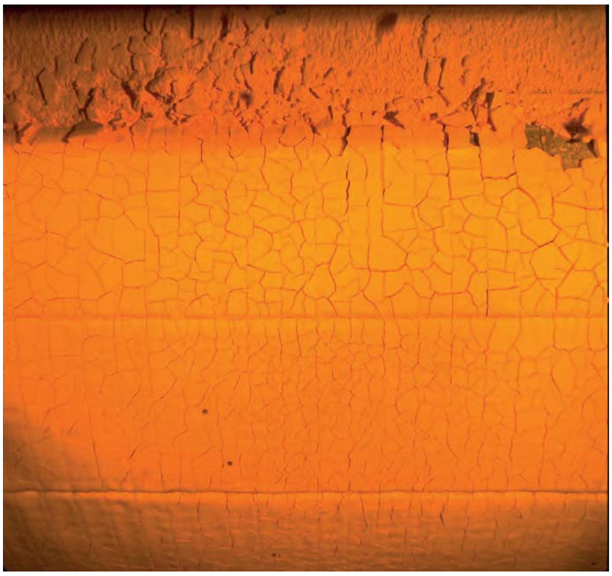

Fig. 2: "Yellow cake" at the Comurhex plant for conversion of natural uranium into UF_4 in Malvési, France.

Uranium Conversion and Enrichment

The principal activity of the Chemistry Business Unit is to provide conversion services for natural uranium as uranium hexafluoride (UF_6). The uranium extracted from mines, concentrated in the form of "yellow cake" and already under the ownership of the operator of the plant cannot be used in this state in nuclear reactors of electricity production. To be used as a fuel, it must be transformed. The conversion operations consist of transforming the concentrated ores into uranium hexafluoride (UF_6), giving it the purity needed for the fabrication of nuclear fuel. These conversion operations represent an essential stage in the fuel cycle between mining activities and enrichment of the uranium.

The conversion of uranium concentrate obtained from mines is carried out through a process of chemical transformation in two stages:

- Transformation of natural uranium into uranium tetrafluoride: During the first phase, the uranium is transformed into uranium tetrafluoride (UF_4). The concentrated ore is dissolved by acid, and then purified to yield. After precipitation and calcination, uranium trioxide powder (UO_3) is obtained, and is then hydrofluorated using hydrofluoric acid. It is thus transformed into a green substance with a granular appearance called uranium tetrafluoride (UF_4).
- Transformation of uranium tetrafluoride into uranium hexafluoride: The UF_4 is then converted in a second phase of fluorination into uranium hexafluoride (UF6), using fluorine obtained by electrolysis of hydrofluoric acid. The UF_6 is made by contact of gaseous fluorine with the UF_4 powder. The chemical reaction makes very high-temperature in a reactor with flames. A last stage consists in transforming the obtained UF_6 of the solid state to the gaseous state. Thus, it's possible to enrich it.

The majority of reactors use uranium containing between 3% and 5% uranium-235 as fuel. Natural uranium contains only 0.7%. It is therefore necessary to increase the concentration of uranium-235 to obtain a fuel that can be used in nuclear reactors. This is called enrichment. AREVA uses the industrial process of centrifugation in Georges Besse II plant located at Tricastin (Fig. 3).

The Tricastin site in South France is the setting for all industrial operations involved in transforming uranium, originating from mines, into fuel for nuclear power plants. It includes six plants, which together cover the entire production chain.

Fig. 3: Georges Besse II enrichment plant, inaugurated on 14th December 2010 at Tricastin (France).

Nuclear Fuel Assembly

Fuel assemblies for pressurized water reactors and boiling water reactors are produced at different AREVA subsidiaries worldwide. Entities of the Group hold the operating permit or license for fuel fabrications in Lingen, Germany, as well as in Richland, United States, and Romans, France.

As a prerequisite for further steps, uranium hexafluoride is converted to uranium dioxide powder. In pellet production, the uranium dioxide powder is processed to uranium pellets. A uranium pellet weighing 7.5 grams and enriched to 4.3 % contains as much energy as 1,000 kilograms of hard coal. This equals the annual power consumption of 3,000 kilowatt hours – as much as an average German household requires.

Fig. 4: Pressurized water reactor assembly at the fuel fabrication plant in Lingen, Germany.

The next step is the fuel rod production. In this production step, the pellets are inserted into the zircalloy cladding tubes. Zirconium is the reference material for manufacturing of fuel assemblies. It guarantees uranium pellets' confinement within the reactor thanks to specific qualities: excellent resistance to corrosion, mechanical strength, stability under irradiation and low absorption of thermal neutrons. Fuel rods constitute the nuclear reactor's first safety barrier.

After fuel rod production follows the assembling of the final product. The production of the fuel assembly for pressurized water reactors starts with the assembly of the support structure. The assembly structure grids and the guide tubes are welded to a mechanically stable supporting structure (cage). The fuel rods are fully inserted therein according to a predetermined loading plan. Afterwards, the upper and lower tie plates are installed. Finally, the fuel assembly is cleaned, subject to a comprehensive final test and stored hanging in subsurface fuel assembly storage until dispatch (Fig. 4).

Fig. 5: Introduction of the second Steam Generator into the Reactor Building at Flamanville 3 EPR reactor, France.

Nuclear Power Plants under Construction throughout the Word

According to the International Atomic Energy Agency (IAEA) there are worldwide 440 Nuclear Power Reactors operational and 68 under construction (March 2015).

AREVA's New Builds business is involved in every phase of the design of nuclear steam supply systems and nuclear islands. With a broad range of reactors, the company is in charge of proposals for new reactors and executing these projects from the standpoint of engineering and resources. The Equipment business unit designs and manufactures welded and mechanical components for the nuclear island, principally heavy equipment, including large forged parts and mobile equipment. Its expertise in heavy and mobile component manufacturing guarantees the provision of quality, reliable parts to its customers.

Currently, there are four EPR reactors under construction in Finland (Olkiluoto 3), France (Flamanville 3) and China (Taishan 1&2) (Figs. 5, 6, 7). Furthermore, the British government is pursuing a program to replace its nuclear fleet. In particular, the power company EDF Energy plans to expand the Hinkley Point site (current generating capacity: 870 MWe) with two EPR reactors. The EPR is the first third-generation Pressurized Water Reactor (PWR) to have achieved the market breakthrough. The electrical power of the EPR (around 1600 MWe) is higher than that of the most recent plants (around 1450 MWe).

The ATMEA1 reactor is another third-generation PWR built on extensive nuclear reactor knowledge. The ATMEA Company is a joint venture between two global leaders in nuclear reactor design: AREVA and Mitsubishi Heavy Industries (MHI). Following several years of design development, the medium-power reactor provides a credible solution for projects in emerging nuclear economies or locations in which a medium-power solution is more suitable.

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Fig. 6: EPR construction site in Olkiluoto, Finland.

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Fig. 7: Taishan 2 EPR construction site, China.

Products and Services for Nuclear Power Plants in Operation

Providing services for nuclear power plants in operation is another core business of AREVA. The integrated services offer corresponds to a fundamental change in the market: power companies are focusing on programs to extend the operating period of their power plants. This is managed with customers in long-term partnerships, with a global approach to component lifecycle management and power plant servicing and maintenance. Activities are mainly carried out during power plant outage periods, called unit outages, which take place every 12, 18 or 24 months depending on the reactor's operation mode.

The Installed Base business unit is structured to achieve an optimal balance between global reach and local presence. It is able to mobilize resources, skills and equipment throughout the world and provide customers with local offers and personalized services. With specialists worldwide, the Installed Base business unit can quickly deploy highly qualified, experienced teams to meet customers' specific needs at over 100 nuclear power plants.

Fig. 8: MOX fuel fabrication at MELOX plant, Bagnols-sur-Cèze, France.

Used Nuclear Fuel Recycling

Industrial solutions are offered to reduce nuclear power's environmental footprint, in particular in the recycling field, which involves recovering recyclable materials from used fuel and fabricating new fuels for use in reactors.

La Hague plant located in the La Manche region provides the first stage in the recycling of nuclear used fuels. This industrial operation meets a raft of energy and environmental considerations. The facility has the industrial capacity necessary for the annual processing of used fuel from 80 to 100 nuclear reactors, amounting to 1,700 tons. This makes AREVA the biggest operator in the world in the processing of nuclear fuel. Since its entry into service in 1966, the company's site at La Hague, the leading industrial center of its type in the world, processes nuclear used fuel for subsequent recycling – fuel which has been replaced in nuclear power plants.

Once discharged from the reactor, the used fuel contains 96% recyclable material (95% uranium and 1% plutonium), which will be reused to produce electricity and just 4% waste (fission products and minor actinides). Processing, the first step in recycling, is a high quality service. Throughout the process, the nuclear materials in the used fuel remain the property of customers. AREVA La Hague receives used fuel sent by French and foreign electricity companies. In accordance with French law the waste taken from used fuel from foreign electricity companies are returned to their country of origin after processing and French waste is temporarily stored onsite pending a permanent storage facility.

Created from a mixture of uranium oxides and plutonium, MOX fuel enables the recycling of plutonium issuing from used fuel recovered during treatment operations executed at the AREVA La Hague recycling site. MELOX facility, located on the Marcoule nuclear site in Gard region of France, produces MOX fuel assemblies intended to feed light water reactors (Fig. 8). First, a primary mix is created, using plutonium oxide and depleted uranium oxide, and "chamotte" powders obtained from discarded pellets. Depleted uranium is added to this primary mix to obtain the exact concentration required by customers. Concentration of plutonium constitute of a fuel assembly (ranging from 3-12% concentration). The fabrication of MOX (mixed oxides) fuel is similar to that of uranium oxide fuels.

The recycling of recovered materials (uranium and plutonium) enables savings of up to 25% in natural uranium needs as well as reductions in the volume and toxicity of end waste, to a large extent, through processing and conditioning designed to suit each type of waste (Fig. 9).

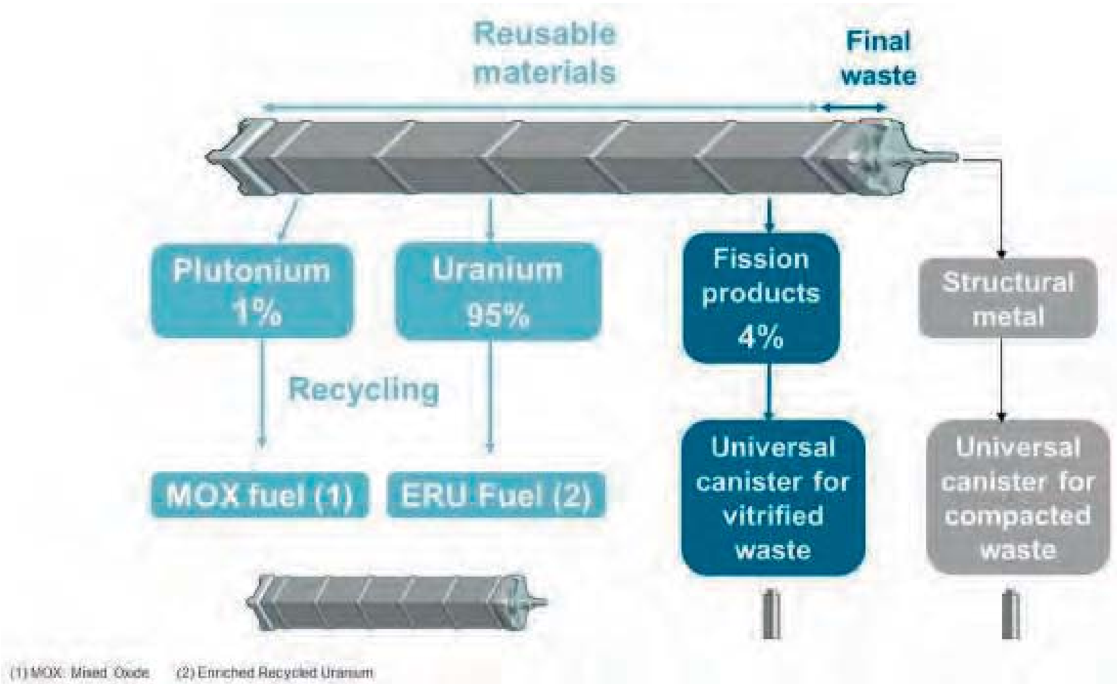

Fig. 9: Composition of light water reactor fuel when unloaded.

Dismantling and Decommissioning

Further to the back end of the nuclear fuel cycle including spent fuel storage and reprocessing, the life cycle of nuclear power plants includes decommissioning, dismantling and waste management. With more than 20 years of experience, AREVA manages and realizes decommissioning and dismantling operations of nuclear power plants and fuel cycle facilities. Based on this comprehensive experience, The company has developed and now successfully applies most efficient methods and processes improving productivity of dismantling works as well as treatment and packaging of resulting residues. The Managing Board has decided to establish the company's global competence center for reactor dismantling in Germany.

The company draws on a wide range of experience for this development work. In recent years, the company's dismantling experts took part in the successful dismantling of German nuclear power plants in Stade (Lower Saxony) and Würgassen (North Rhine-Westphalia). Before the dismantling of those nuclear power plants which were shut down in 2011 can begin, politicians still have to define a few important parameters. The firm commitment to a deadline for the commissioning of a permanent disposal site for highly radioactive and heat-generating waste is decisive in this regard. It is needed to plan the processes for the upcoming years.

Nuclear Competencies

Safety is AREVA's premise for success in the nuclear industry. The safety of the group's own operations is summarized among this objective just as the abilities to increase the safety of costumer's sites and ensure the safe operation of their plants.

Today increasing needs for reliable energy supply are combined with efforts to reduce greenhouse gas emissions and save natural resources all over the world. Nuclear energy is one of the best answers to comply with both requirements at the same time. Hence many countries are pressing ahead with nuclear projects – western OECD-countries like the UK and Poland as well as emerging countries like China.

Supreme safety standards characterize the company's position among the suppliers of nuclear technology. The German region provides many of the safety features and contributes to both new build as well as modernization projects of the group. These global activities are the economic premise to preserve the nuclear competencies in Germany.

Beyond its comprehensive nuclear portfolio the company also is investing in renewable energies to develop, via partnerships, high technology solutions and is working on new technologies for energy storage. Resources and know-how from the nuclear industry are also required in other industries. For example, the company is delivering solutions to enhance the safety in aviation, railway and steel business and contribute to quality and safety.

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