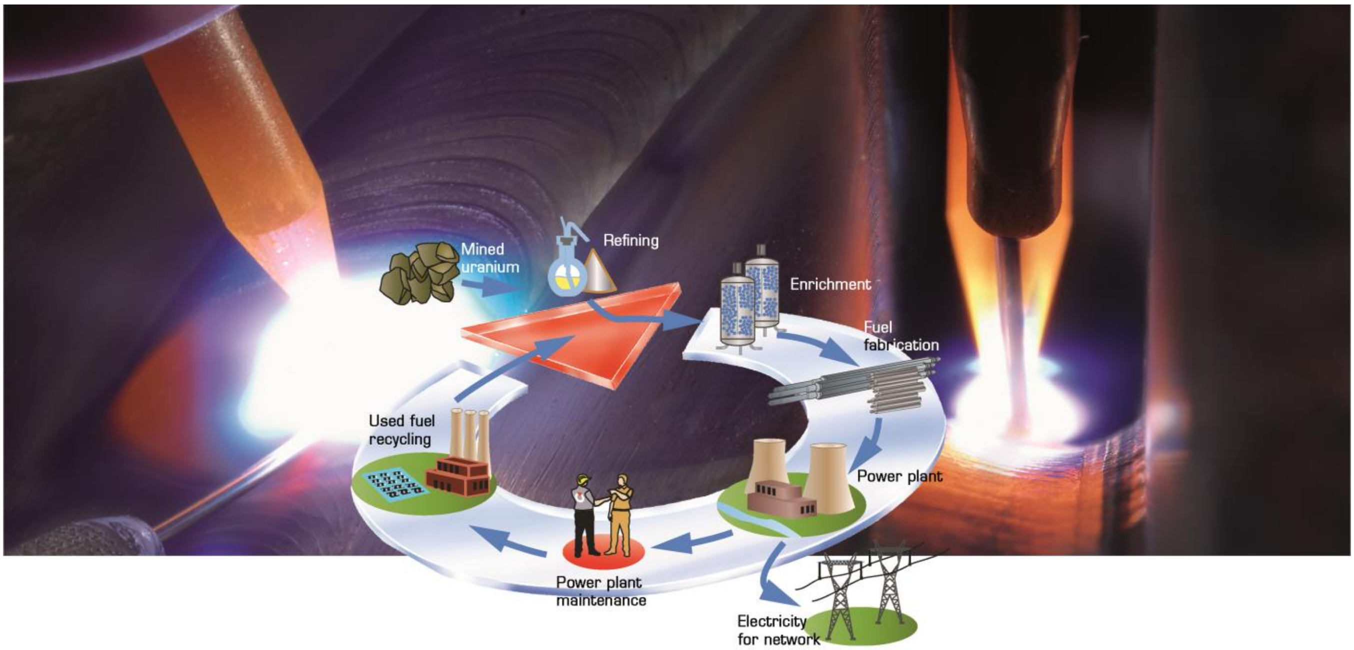
POLYSOUDE
THE ART OF WELDING

Press Release

INNOVATIVE WELDING SOLUTIONS FOR THE NUCLEAR INDUSTRY



Introduction

“The design and manufacturing of welding equipment for nuclear power production is one activity among Polysoude’s wide range of applications”, Hans-Peter Mariner, the group’s Chief Executive Officer reports “. In this field, the company is involved from the first stage up to the very end.” Experts classify the mining of uranium ore and isotope enrichment as the front end of the nuclear fuel cycle. (Fig. 1)

As the heads of the rock drills, which are used to explore uranium deposits, are joined to their shafts by means of Polysoude welding machines, the company is situated even a bit ahead of the front end" Mr Mariner adds smilingly. (Fig. 2)

But, of course, the heavy components of the Nuclear Island, i.e. a reactor vessel, steam generator, pump, pressuriser with related primary coolant loop circuit as well as the parts of the Conventional Island such as turbines and condensers which are manufactured and installed using Polysoude equipment also.

However, Mr Mariner recalls: "When the company was founded in 1961, TIG-welding was regarded as a very exotic process. Not only the cost-intensive equipment but also the limits of simply joining thin-walled tubes in single-pass-stringer-bead technique at a very low productivity prevented decision-makers from getting involved. Only the achieved outstanding weld quality and the reliable welding process encouraged the former pioneers to continue."

Today, these objections are over-come. The development of pulsed current allows all-position welding (orbital technique) and the application of Arc Voltage Control (AVC), accompanied by torch oscillation, enabling effective multi-layer welding without interruption. The improvement of power source characteristics (output power, response time, fast pulsation) results in full function sources; a successful application of alternating current AC with AVC stands for state-of-the-art welding of aluminium and its alloys. Besides, the initiation of hot wire welding leads to increased cost effectiveness whereas the introduction of narrow-gap welding in conjunction with hot wire technique allows economic joining of thick-walled workpieces (Fig. 3).

Endless rotating collector welding heads open the door to inside and outside welding, cladding and buttering operations even on workpieces with complex geometry. Equipped with various combinations of the cited techniques, completed by video monitoring, remote control, robot-supported servicing as well as data acquisition on tailor-made installations, designed and manufactured by Polysoude, are today operated in virtually all fields of nuclear energy production. "But nevertheless," Mr Mariner emphasises, "I must not forget to point out our support at the back end of the nuclear fuel cycle. Thoroughly planned maintenance and appropriate repair of the facilities guarantee the safety of all, whereas recycling of used fuel and sustainable nuclear waste disposal are a valuable contribution to the protection of our environment."

The examples below represent custom-built installations for various clients that use a wide range of diverse technologies. They represent only a partial view of Polysoude's capabilities

Enrichment

In order to meet the requirements of a controlled nuclear reaction, the concentration of the fissionable isotope U-235 must be increased from naturally 0.7 % of its weight in mined uranium to about 5 % in nuclear fuel.

Different techniques are actually applied or emerging for the enrichment; the most common are gaseous diffusion and the use of gas centrifuges. The head of Polysoude believes: "from a welding engineer's point of view, both methods constitute the same challenges." Solid uranium hexafluoride (UF_6) must be heated and converted to the gaseous state. For the following treatment the gas must be passed through a complex system of pipes and vessels, before it is finally condensed back into a liquid, filled into canisters and cooled down to become solid. In order to withstand the chemical corrosiveness of UF_6, all surfaces in contact with the gas must consist of metals such as nickel or aluminium. Furthermore, the installation must be totally leak-tight; the UF_6 gas must to be contained reliably inside and the oxygen in the ambient air must be prevented from penetrating into the system.

Most of the piping must be installed and joined directly inside the plant under construction, which means restricted access to the welding areas and the necessity of all-position welding. "These conditions are perfectly met by the orbital welding equipment designed and manufactured by Polysoude", Mr Mariner states. Mobile power sources are adapted to the harsh on-site conditions including humidity and unstable energy supply; with open MU IV orbital welding heads and low profile open carriage-type welding heads of the Polycar 30 family, thousands of high quality joints can be made one after another in automatic mode without any weld defects. (Fig. 4)

With the tungsten electrode connected to the negative pole of a direct current power source and helium as protective gas mechanised TIG-welding of aluminium and its alloys can be carried out up to wall thicknesses of 6.5 mm; thicker tubes demand a J-preparation of their ends. "After recent research efforts Polysoude has managed to implement arc voltage control on equipment for AC-welding of aluminium and even provides a performance guarantee", the CEO points out enthusiastically. "Arc voltage control (AVC) is a technique to keep the arc length stable, thus allowing fully automatic multi-pass welding which means greatly improved productivity. Commonly used for pulsed DC welding current, only few manufacturers worldwide are capable of applying AVC on AC current and to use it for aluminium welding." (Fig 5)

Nuclear fuel fabrication

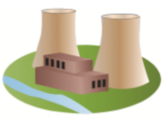
The final processing of enriched solid uranium hexafluoride (UF_6) is carried out in nuclear fuel fabrication facilities. (Fig. 6)

In such facilities UF_6 is converted chemically to uranium dioxide (UO_2) powder, which serves as raw material for the preparation of small pellets. These are filled into rods that have to be closed and put together for fuel assemblies.

The thin-walled tubes which are used to produce these rods usually consist of a zirconium alloy. The extremities of the tubes are sealed gas-tight by means of welded end caps. Mr Mariner describes: "To set the first end cap, Polysoude has developed special high precision lathes which provide the end cap in the required position and weld it to the tube". The weld is carried out without the addition of filler wire. The tube itself is clamped by a horizontal hollow head stock and rotates during the welding operation, the TIG torch remains fixed in the 1G (12h) position. Due to the perfect control of all parameters of the TIG welding process any damage of the thin tube walls or end caps by too strong penetration can be excluded; for quality assurance purposes the equipment is often completed by a weld data acquisition and recording system. (Fig. 7)

The second end cap must be welded with the UO_2 pellets already stacked into the tube, so the environmental conditions exclude any direct intervention of the operator. To prevent the pellets from falling out, the tube is clamped in the welding unit in vertical orientation. The TIG torch is positioned above the tube; neither the torch nor the tube rotates during the weld cycle. Controlled by a magnetic field, which is generated by a special device ("dump") situated next to the torch, the arc is guided along the circular path of the welding seam on the outer edge of the tube. (Fig. 8)

After having passed quality control, the finished nuclear fuel rods are put into a particular frame and become a fuel assembly. A so-called cage is typically composed of 200 to 300 rods; its length is about 4 metres. During operation these frames and the rods are exposed to severe stress resulting from high pressure, elevated temperatures and strong radioactive radiation in the core of a nuclear reactor. Excellent design and workmanship are required to guarantee sufficient mechanical and geometrical stability of the construction. The load-bearing elements of a fuel assembly are the bottom nozzle that guides the assembly during its introduction into the reactor, a central channel and the top nozzle to which the hoisting equipment is fastened. Polysoude is in a position to provide specially designed welding equipment to join the lower and upper part of the fuel assembly to the channel. (Fig. 9)



Nuclear power plant

The processes presented below are adapted to various types of plant construction.

The components of the primary cooling circuit of a nuclear power plant belong to the Nuclear Island. The centre of this circuit is formed by the reactor vessel with its reactor vessel head. Heat is released by a nuclear chain reaction provoked by the nuclear fuel inside the rods in the middle of the reactor. Control rods are suspended from the vessel head; raising or lowering them by means of the control rod drive mechanism to allow accelerating or decelerating the chain reaction, thus generating more or less heat.

The reactor vessel is filled with water, which becomes hot. A pressuriser is used to keep the pressure in the system at the desired value; therefore electric heating elements are installed inside.

The heated water circulates in the primary loop and pumped through the steam generators. These are heat exchangers, i.e. vessels carrying a large number of tubes inside. The heat is absorbed by the water of the secondary cooling circuit, which flows through these tubes and converts to steam. Via a turbine the steam of the secondary loop drives a generator to produce electricity. The turbine and the generator are part of the Conventional Island of a nuclear power plant.

The welding of the heavy components is carried out as far as possible during prefabrication in a workshop using stationary welding equipment. For example, the core barrel is placed on a turntable and rotates during the weld operation; two welding torches are installed opposite on column and boom devices and weld simultaneously. Narrow gap welding equipment and control devices for the synchronisation of the weld cycle and the different movements are designed and manufactured by Polysoude. (Fig. 11)

The reactor vessel and the steam generators are made of forged parts with nozzles, which are called safe-ends. These have to be joined to the pipes of the primary coolant circuit. As the materials of the pipes and the components are different they cannot be connected easily on site. A buttering operation on the sides of the nozzles prepares the heterogeneous joint. During this operation a deposit is welded on the side of nozzles, which is meant to create a transition zone between the different metals. Buttering can be carried out during pre-fabrication in the workshop, whereas the final connection must be finished on-site with a homogenous weld between two stainless steel parts. (Fig. 12)

The inner surfaces of the reactor vessel and the steam generators are protected against the corrosive attack of the coolant by a resistant layer, the important surfaces are commonly coated in an economical manner by strip cladding. However, strip cladding is not suited for small geometries, so the inside of the nozzles and the section of the pipes with the transition zones remain inaccessible. Mr Mariner proudly remarks: “For this application Polysoude offers specific hot wire TIG welding heads. These collector heads can rotate endlessly and automatically follow the complex geometry at the transition between the vessel and nozzle during the cladding operation.” (Fig. 13)

The manufacturing of steam generators is also carried out using Polysoude welding equipment. To achieve the demanded quality level of the tube sheet coating, the dilution rate between substrate and deposit is strictly limited. The heat input must be kept as low as possible. These are ideal prerequisites for the application of hot wire TIG welding, where heat input and dilution can be perfectly controlled and are accompanied by a high degree of repeat accuracy. (Fig. 14)

Tube-to-tube sheet welding equipment consists of orbital welding heads, which are clamped inside the tube to be welded (Fig. 15). Different models are available for welding with or without filler wire, special protection chambers can be mounted if the cladding layer on the tube sheet is oxygen-sensitive. To increase productivity, distinct levels of automation are possible; with adequate configured power sources several welding heads can be operated at the same time on the same tube sheet.

Special attention needs to be paid to the construction of the reactor vessel head. In particular, the top and bottom parts are complex components with numerous nozzles for control instruments and the Control Rod Drive Mechanism (CRDM). Following the initial design the pressure boundary welds of these nozzles were situated at the inside of the reactor vessel bottom head. In some cases, primary water stress corrosion cracking of nozzle penetrations and welds had been detected. Damage from acceptable local corrosion of parts up to pumpkin sized loss of material occurred, causing frequent plant shutdowns and outage.

Since then, sophisticated production methods have been developed in order to avoid such damage. To connect one of the four CDRM tubes, in the first step carbon steel is welded on the outside of the vessel head until a flat circular surface is attained. During the second step a circular cladding operation with low alloy steel wire is carried out until the specified height of the stud is reached. The inside of the stub is then drilled to the fitting diameter. The third step consists of depositing a protective layer on the inner surface of the stud by means of an internal cladding operation. Du-ring the fourth step the final connection of a stainless steel tube is prepared by a buttering operation on the side of the stud, and in the final step the heterogeneous joint is carried out as girth weld. As a result of these operations none of the welds are in contact with the coolant and all carbon steel surfaces are protected. (Fig. 16)

The operations described above are carried out in the workshop using stationary installations, whereas the connecting pipes between the heavy components of the primary coolant loop have to be assembled and welded with mobile equipment on-site. (Fig. 17)

In order to produce the root pass and the filling passes, low profile open carriage-type welding heads travel on pre-mounted guide rings around the stainless steel pipes, which have outer diameters of usually 862 or 976 mm and corresponding wall thicknesses of 69 or 96 mm. The low profile design of the equipment allows the necessary radial and axial work area clearance to be substantially reduced; welding of tube to elbow joints or tube to tube joints next to obstacles like walls or the ceiling can be carried out.

Mr Mariner asserts that improved productivity is an important matter for on-site operations. In addition to the sophisticated features of the equipment such as automatic control of the complete weld cycle by the power source, motorised AVC and torch oscillation, hot wire welding, cost and time-saving narrow gap technique can be applied as an alternative to a conventional tube end preparation.

Many components of the Conventional Island of a nuclear power plant are also manufactured using Polysoude welding equipment. On site, the tubes of the secondary cooling circuit have to be mounted and connected to the steam generator, the turbine and the condenser.

The condenser itself is manufactured in a workshop. Serving as a heat exchanger, lots of tubes inside a vessel have to be connected to a tube sheet, which is often protected by a previously deposited coating. Indeed, manufacturing procedures and equipment are similar to those already presented for the steam generators of the primary circuit: tube-to-tube sheet welding with or without filler metal using orbital welding heads and coating of the tube sheet with mechanised cladding equipment. (Fig. 18)

The central element of modern steam turbines, the rotor with a length of up to 20 metres and a weight of up to 350 tons, is often assembled from two or more segments. These segments are forged parts and can consist of different alloys. In order to prepare the connection, an intermediate layer is deposited on each of the upper faces of the segments, which are fixed in an upright position on a turntable. To complete the heterogeneous joint, the rotor segments are super positioned and the buttered sides are then welded together using the TIG hot wire narrow gap technique. (Fig. 19)

Maintenance and repair

Preventive maintenance and professionally carried out repairs are essential for the safe and sustainable operation of nuclear power plants. The improved design of delicate constructions, for example the mentioned procedure of connecting the CDRM tubes to the reactor vessel head, helps to avoid unscheduled downtime. Moreover, procedures and equipment have been developed and approved to provide an acceptable level of quality and safety concerning the structural integrity of such repairs. Mechanised, remotely operated welding equipment designed and configured by Polysoude allows respect of the specified procedures and helps to maintain the man-rem exposure of the repair personnel at a low level.

A concern of these repair procedures used to be the Bottom-Mounted Instrumentation (BMI) nozzles in the reactor vessel bottom head. In numerous cases, primary water stress corrosion cracking caused severe damage and leakage in the primary coolant circuit. In this case, the defective BMI nozzle had to be removed flush with the outside of the vessel head. As an intermediate layer, a weld pad was then deposited around the remaining hole in the vessel head, allowing creation of a reliable heterogeneous connection by welding the stainless steel replacement nozzle directly to the pad. Using this method, the original weld at the inside of the head remains intact, however the pressure boundary of the joint is moved to the outside. The described procedure is known and approved as half pipe repair.

Similar problems occurred on boron injection (RIB) nozzles, which are also connec-ted to the primary coolant circuit. An orbital TIG welding head is positioned inside the piping to repair them. An endoscope is used by the operator for remote monitoring. Due to the endless rotation feature of a collector head, cladding of the inner surface of the branch can be carried out continuously without stoppage after each revolution. (Fig. 20)

To pass control equipment, particular nozzles are mounted on the reactor vessel head. The pressure boundary of the primary coolant circuit is constituted by a seal which is called a “canopy joint”. During each refuelling outage of the reactor, the canopy joints have to be disassembled; additional wear can be caused by routine maintenance. Polysoude, specialised in designing and manufacturing remotely operated orbital cladding equipment, proposes a specially-developed welding machine to rebuild the joint. (Fig. 21)

Recycling of used fuel and sustainable nuclear waste disposal

In spent nuclear fuel, when it comes from a reactor, remains a considerable amount of fissionable U-235; the end of use is indeed provoked by the presence of too many neutron absorbers. France is one of the countries where spent nuclear fuel is recycled, so the transport of highly radioactive material to the recycling facilities must be ensured in a reliable manner.

Polysoude is involved in the development of methods to seal the huge transport canisters lastingly using specific welding procedures.

Similar problems occur when the residues from the recycling process and the other radioactive waste must be disposed. Once again Polysoude is required to offer sealing solutions which are expected to last over extremely long periods of time. (Fig. 22)

Summary

“As a global player and leader of the world market with more than 50 years of experience, Polysoude proudly accepts the title *Inventor of orbital welding technology*” Mr Mariner concludes. “The headquarters of the company are based in the French city Nantes, with a worldwide presence in over 50 countries. Highly qualified technical, advisory, training and service personnel take part continuously in the latest developments of nuclear power plant construction and related activities such as uranium mining and enrichment, fuel fabrication, maintenance, service and the protection of environment. Polysoude develops dedicated welding equipment for all types of applications around the nuclear energy production cycle “Last but not least”, concludes Mr Mariner, “we always pay attention to defend our position a bit ahead of the front end”.

Photos

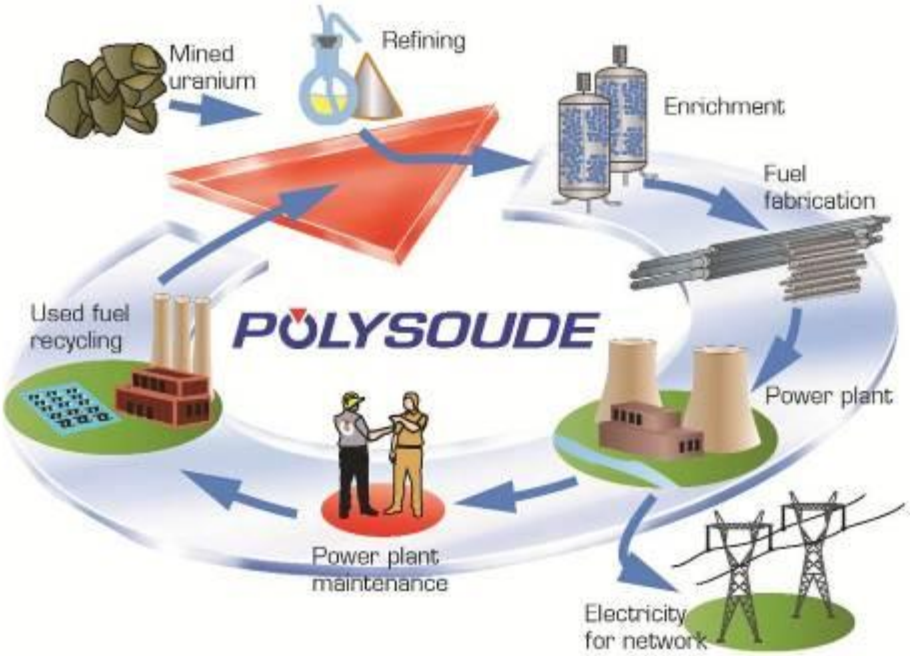


Fig. 1: Nuclear power generation cycle

Fig. 2: Hans Peter Mariner: "In the nuclear industry, Polysoude equipment is recognised for reliable joint quality and proven operation"

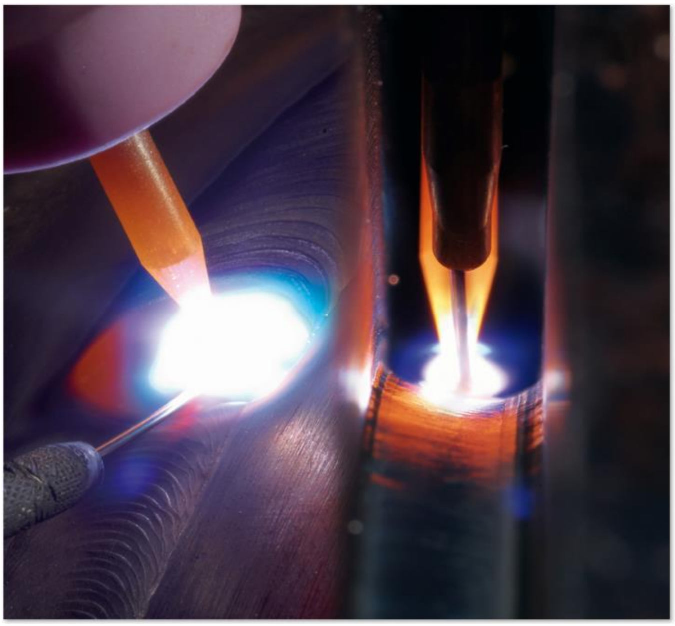


Fig. 3 Conventional hot wire technique leads to hot wire narrow gap

Fig. 4: Complex piping systems in a uranium enrichment facility welded using a Polycar 30 low profile open carriage-type welding head

Fig. 5: Prefabrication of an aluminium manifold using AC welding current with Arc Voltage Control (AVC)

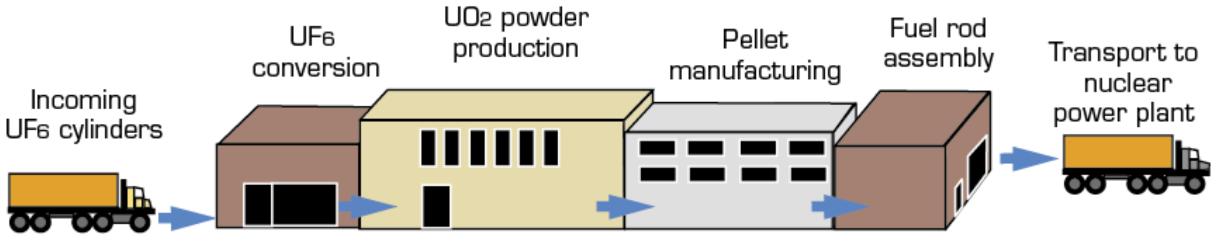


Fig. 6: Nuclear fuel fabrication facility

Fig. 7: Precision vacuum welding lathe for high alloy steel end caps

Fig. 8: End cap welding with magnetic arc deviation

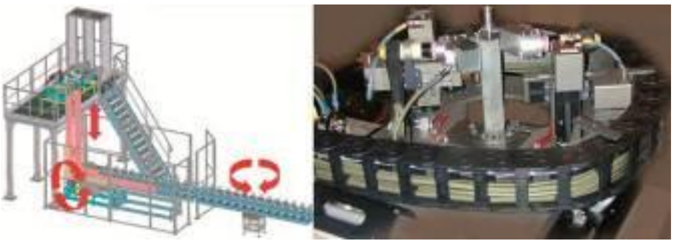


Fig. 9: Welding of bottom and top nozzle onto fuel casings

Fig. 10: Nuclear Island of a pressurised water reactor

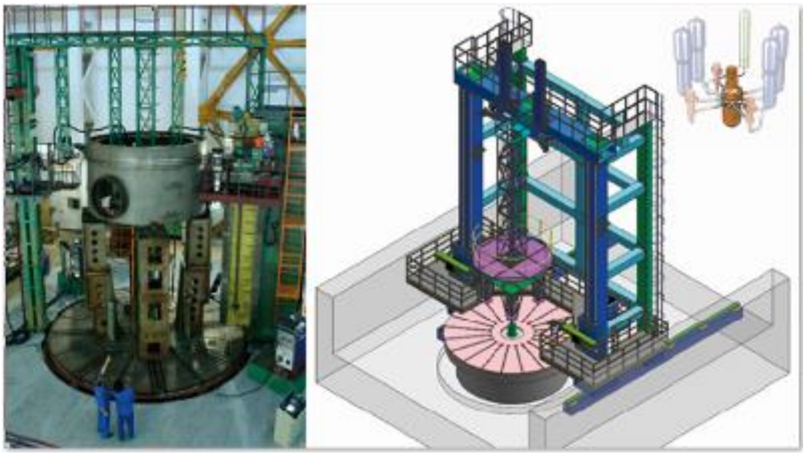


Fig. 11: Reactor core barrel assembly

Fig. 12: Preparation of a heterogeneous joint of the safe-end (buttering operation)

Fig. 13: Safe-end flange welding

Fig. 14: Deposit of a protective coating on a steam generator tube sheet (cladding operation)

Fig. 15: Steam generator tube-to-tube sheet welding using two welding heads

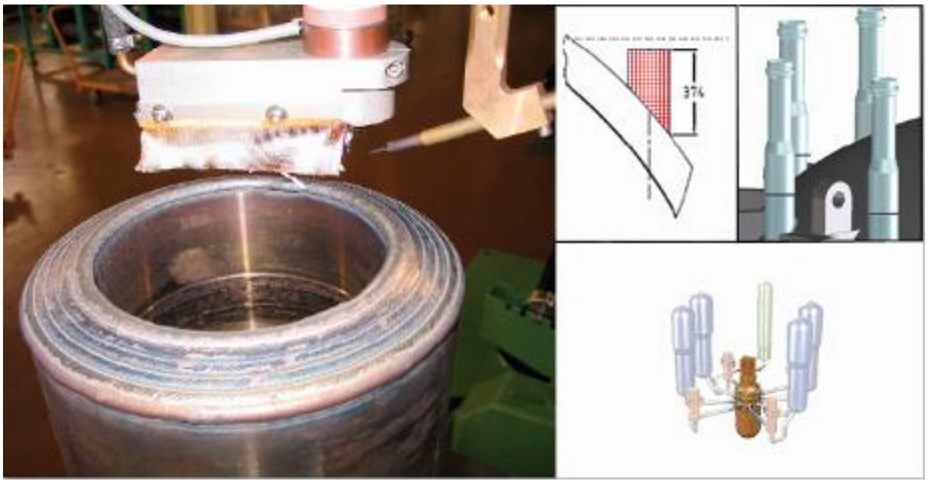


Fig. 16: Control Rod Drive Mechanism (CRDM) adapter build-up

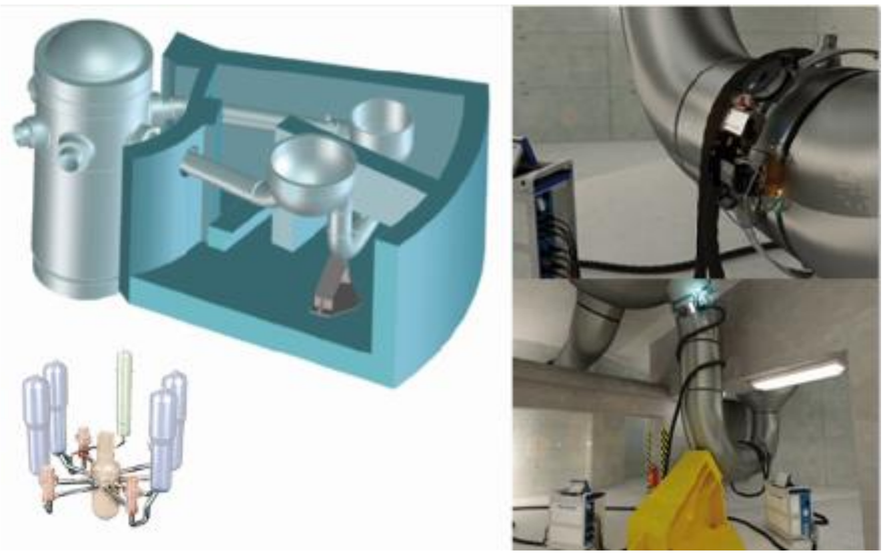


Fig. 17: Pipes of the primary coolant circuit can be welded together next to walls or the ceiling

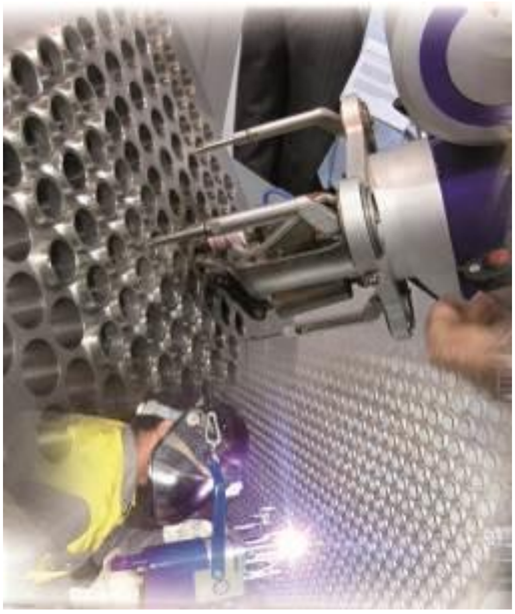


Fig. 18: Condenser tube-to-tube sheet welding

Fig. 19: TIG welding station for joining vertically super positioned rotor segments

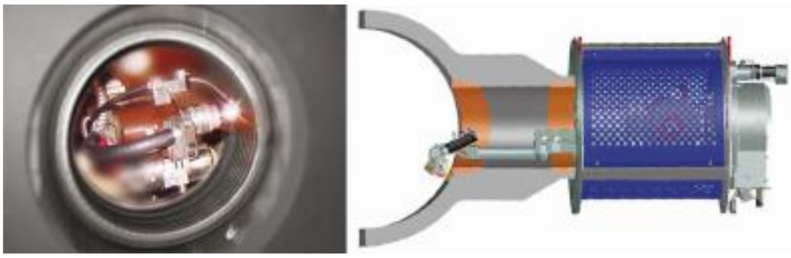


Fig. 20: RIS/RIB (boron injection) nozzle repair using inside cladding operations

Fig. 21: Canopy joint rebuild

Fig. 22: Canister seal welding for recycling of used fuel and nuclear waste disposal

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