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Paper

WATER ABRASIVE SUSPENSION (WAS) CUTTING

UNDER WATER IN DECOMMISSIONING

NUCLEAR POWER PLANTS

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ABSTRACT

Electrical power generated by Nuclear Power Plants (NPPs) is an established technical standard since the latter half of the 1950's. NPPs are designed to operate for a specific period. Many NPPs are subject to become decommissioned during the next years and decades.

The fact that a NPP, even after shut down, costs significant amounts (e.g. US$ 100,000) each day explains the NPP's owners strong interest to decommission the nuclear specific components in a safe and timely manner.

From a technical perspective the major challenge in decommissioning NPPs is the deconstruction of the radioactive contaminated components. Working in radioactive contaminated environment indispensably requires remote operated systems.

Today, dismantling and disposal of nuclear contaminated structures of pressurized water reactors and boiling water reactors such as the reactor pressure vessel and the internals of the reactor pressure vessel by Water Abrasive Suspension (WAS) jet cutting is a proven standard. In this application WAS cutting technology can be utilized both in normal atmosphere (air) and under water.

This paper explains the cutting task, the challenges for a WAS jet cutting system and the system components used to meet the challenge.

1. INTRODUCTION

In December 2008 the number of 438 NPPs, operated in 31 countries worldwide, have generated approx. 390 GW electrical power. More than half (228 NPPs) of all NPPs were erected in the 1980's. Few NPPs have been shut down already, many more are subject to become decommissioned during the next years and decades. Additionally, targeted to provide security of energy supplies but as well for environmental reasons (e.g. reduction of carbon dioxide), nuclear power experiences a renaissance across the globe, with large numbers of new NPPs planned to be installed or replaced in next future.

Due to the sensitive nature of working in contaminated areas and with contaminated materials, decommissioning of NPPs is generally supervised by public authorities and by technical inspection bodies. For the decommissioning of e.g. the reactor pressure vessel or the internals of the reactor pressure vessel these bodies audit the technologies and systems to be utilized for an individual dismantling task. Targeted to secure safety of operation, full scale mock-ups with special care for contingency plans are compulsory!
For the same safety reason, generally only contractors who have proven their nuclear specific know-how and work experience are invited to offer their services for decommissioning tasks.

The following information reflects experiences and data taken from the dismantling of the internals of the reactor pressure vessel of a pressurized water reactor, which was conducted by WAS jet cutting. WAS jet cutting has furthermore successfully been utilized in dismantling the reactor pressure vessel itself.
This paper takes reference to two realized decommissioning projects of internals of the reactor pressure vessel a) at NPP "Würgassen" and b) at NPP "Stade" in Germany. Owner of both NPPs is E.ON Kernkraft GmbH, Hanover/Germany. General contractor for these complete and complex decommissioning projects was AREVA NP GmbH, Erlangen/Germany, to whom ANT supplied turn-key WAS jet cutting systems.

2. THE CUTTING TASKS

2.1. Cutting the Internals of a Reactor Pressure Vessel Under Water

2.1.1. Objects to be Cut

During operation of a NPP the main function of the internals of a reactor pressure vessel is to position and hold the nuclear fuel elements. The following sketches show the typical design of the complex shaped grids and supports as well as especially developed manipulation systems to guide the WAS jet cutting nozzle.

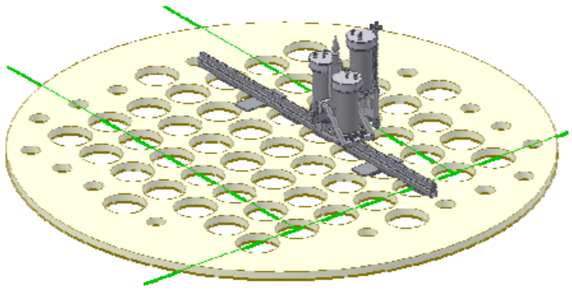


Figure 1: Upper Grid Cover Plate
- Cutting with Linear Manipulation System, max. cutting length: 2,800 mm, material thickness: 49 mm

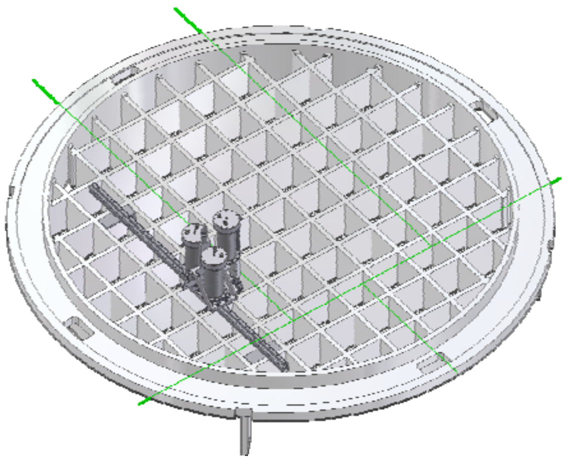


Figure 2: Upper Grid Weir Plate
- Cutting with Linear Manipulation System, max. cutting height: 385 mm, material thickness: 35 mm
- Cutting the edges with ring chassis, max. cutting length: 250 mm, material thickness: 85 mm

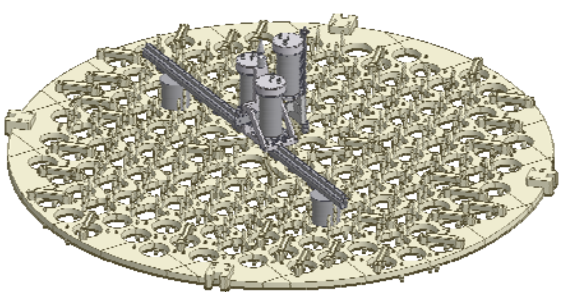


Figure 3: Upper Grid Base Plate
- Cutting with Linear Manipulation System, max. cutting length: 2,800 mm, material thickness: 40 mm
- Cutting the edges with ring chassis, max. cutting length: 250 mm, material thickness: 85 mm

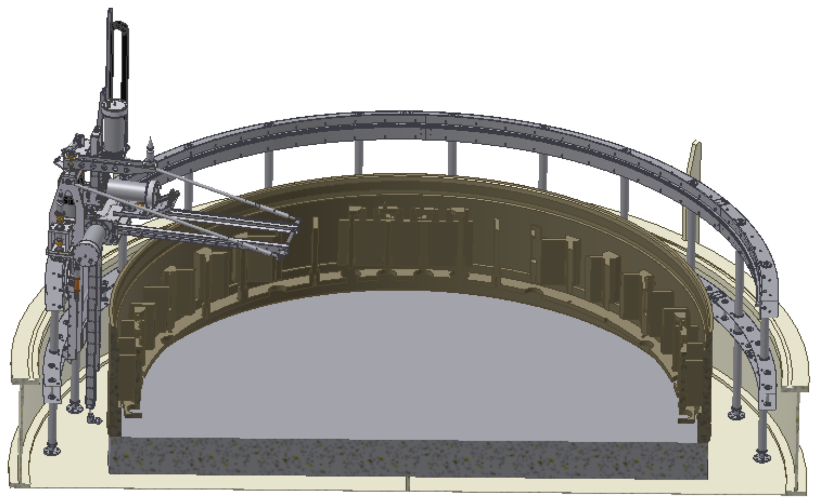
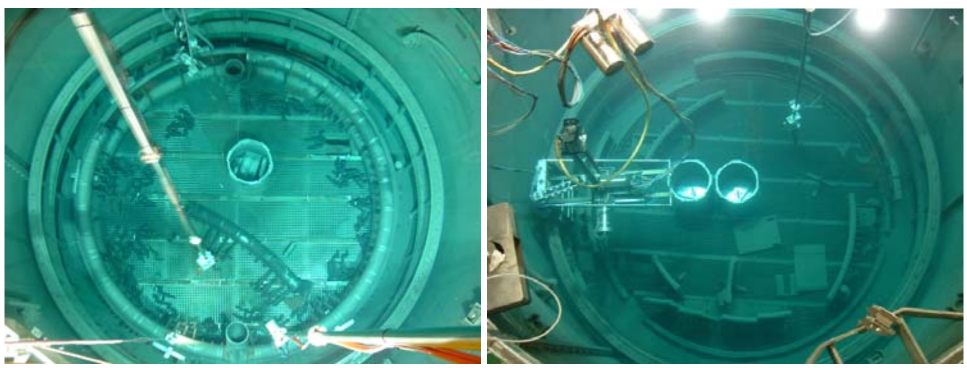


Figure 4: Lower Grid Plate Assembly
- Cutting with ring chassis, max. cutting length: 750 mm, material thickness: 75 mm



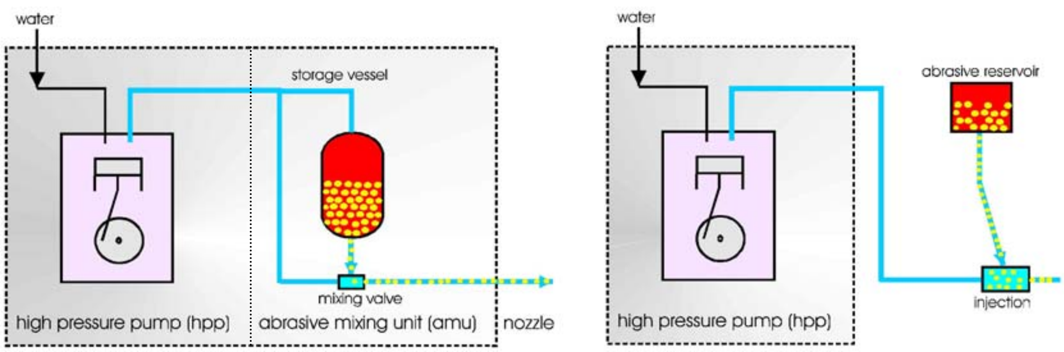
Figures 5 and 6: In-situ images of NPP “Würgassen”

3. SUITABILITY AND BENEFITS OF WAS CUTTING IN NPPs

Different for the widely known Water Abrasive Injection jet cutting technology in WAS jet cutting technology water and abrasive is mixed in a determined mixing unit, the so called Abrasive Mixing Unit. In the Abrasive Mixing Unit the abrasive is stored in wet condition in a high-pressure vessel. During operation the vessel is pressurized by the water supplied by the high-pressure pump. In the complete WAS jet cutting system there is no presence of air, which - besides the 4 times higher cutting performance - offers a significant benefit for operation in NPPs: The WAS jet cutting process happens without generation of aerosols, which is to be avoided in NPPs, as aerosols are exposing nuclear radiation to the air in the NPP.

Suitability for operation in NPPs is further derived from the high flexibility WAS cutting systems offer - especially in areas with limited access. Due to flexible hoses as well as small size nozzles and nozzle holders the cutting tool can reach even otherwise inaccessible sections of complex internals of reactor pressure vessels.

Since 1996, in Germany the WAS jet cutting technology was developed by ANT Applied New Technologies AG (ANT) in cooperation with the University of Hanover/Germany to meet industrial standards and demands. Today, efficiently and stable operating WAS jet cutting systems are available from ANT.



Water Abrasive Suspension (WAS) jet cutting system

Water Abrasive Injection jet cutting system

Figure 7: Operation schemes of WAS jet cutting system and Water Abrasive Injection jet cutting system

4. THE WAS JET CUTTING SYSTEM IN NPPs

4.1. General Configuration of a WAS Jet Cutting System for NPPs

WAS jet cutting systems consists of 5 major components:

- A high-pressure pump
- An Abrasive Mixing Unit (AMU)
- A flexible high-pressure hose
- A dedicated cutting nozzle
- A dedicated manipulation system
- An efficient water treatment system

The following graph shows the configuration of a WAS jet cutting system:

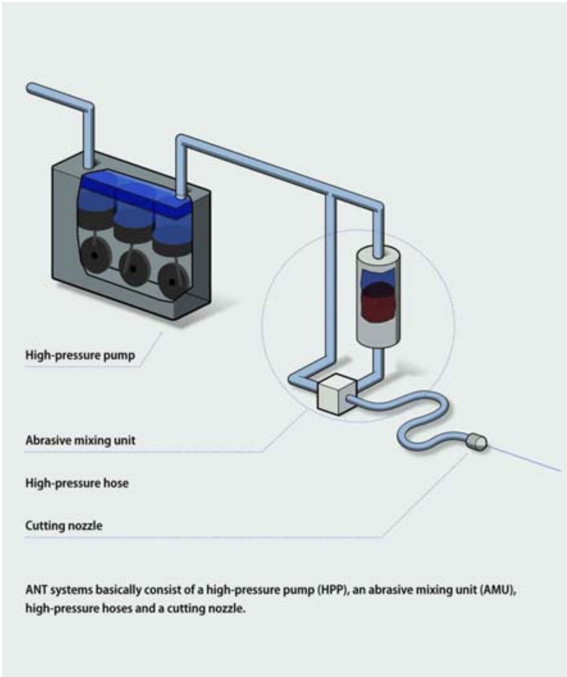


Figure 8: Configuration of a WAS jet cutting system

WAS jet cutting systems suitable for decommissioning of internals of reactor pressure vessels offer 2000 - 2500 bar operating pressure. The cutting nozzle has a diameter of 0.6 - 1.0 mm. Garnet as an abrasive has proven to be very suitable for applications in NPPs. To achieve best cutting performances and filtration capabilities, high quality garnet with minimum percentage of silt is recommended.

4.2. High-Pressure Pump

A high-pressure pump offering 2000 - 2500 bar operating pressure and 10 - 30 l/min. water flow is best suitable for operation in NPPs. The high-pressure pump - driven by an electric motor and controlled by a frequency inverter - is situated outside the so called “Radiation Control Area”, which is the area of radioactive contamination.

4.3. Abrasive Mixing Unit

The Abrasive Mixing Unit (AMU) receives the high-pressure water flow from the high-pressure pump. Designed to offer the best possible combination of high cutting power, efficient use of abrasive and long uninterrupted operation time, typically an AMU with 2000 bar operating pressure and storage capacity of 80 kg abrasive in a 40 l high-pressure vessel is chosen. A key component with AMU's supplied by ANT for underwater applications is a dedicated mixing valve (ANT design and patents), which mixes water and abrasive under operating pressure in a weight-proportion of 90% water and 10% abrasive. Practically this means that e.g. a water flow of 10.0 l/min. contains 1.0 kg of abrasive.

4.4. High-Pressure Hose

A flexible high-pressure hose connects the AMU with the nozzle-holder, which carries the cutting nozzle. Conventional high-pressure hoses with thermoplastic outer and inner liner are offered by several special manufacturers.

4.5. Cutting nozzle

In a typical configuration for operation in a NPP the WAS jet cutting system operates at 2000 bar and a cutting nozzle of 0.6 mm diameter. In this example the hydraulic power at the nozzle is 32 kW. This specification allows underwater cuts through 8" (approx. 200 mm) of steel at a traversing speed of approx. ½ inch/min. (12 mm/min.).
The cutting nozzle is fixed in a nozzle-holder and guided by the manipulation systems described in chapter 4.6. . At the end of its lifetime - after approx. 10 hours of use - the cutting nozzle is replaced easy and fast by the operator; neither adjustment, nor focusing of the tungsten-carbide made nozzle is required!

4.6. Manipulation Systems

4.6.1. Generals on Manipulation Systems utilized in NPPs

In a typical configuration the WAS jet cutting system operates at 2000 bar operating pressure and 0.6 - 0.7 mm cutting nozzle, demanding 10 - 13 l/min water from the high-pressure pump and creating 30 - 45 kW hydraulic power at the nozzle. Due to the concept of working with high operating pressure and low water flow rates, the reaction forces of the cutting nozzle are below 250 N (equivalent to 25 kg). This allows the design of lightweight and compact manipulation systems to guide the cutting nozzle.
Kerf/cut widths of e.g. 1.0 mm require very precise manipulation systems to achieve little tolerances for effective cutting. In operations under water this requirement is of even higher importance as the abrasive water jet is affected by the surrounding water, thus reducing the cutting power.
To allow cutting of complex structures multi-axial manipulation systems are required. All axes are individually remote operated and either servo hydraulic or servo electric driven.
A so laid-out manipulation system offers jitter-free and constant movement of the cutting nozzle.

4.6.2. The Linear Manipulation System

The linear manipulation system is flexibly fixed by pneumatic clamping mechanics in the holes of the different grids and plates to be cut. The cutting nozzle can be moved by 3 axes in x, y and z direction, allowing to cut-off the individually shaped sections.
For safety reasons the drives are locked by sealing air. A position sensor is an integrated component to the Control Unit. It reports the current location of the cutting nozzle.

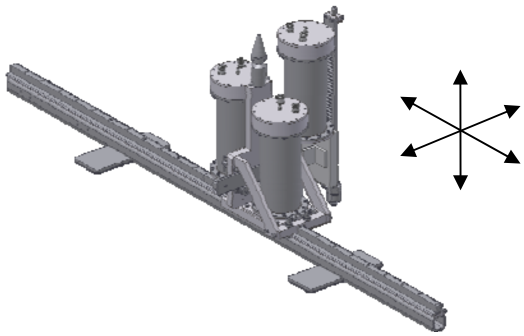


Figure 9: Linear Manipulation System
- 3-axis servo electric manipulator, max. traversing path: x = 300 mm, y = 3,000 mm, z = 500 mm

4.6.3. The Ring Chassis

Targeted to meet the flexibility requirement and to allow cutting complex shaped sections of the internals of the reactor pressure vessel and the reactor pressure vessel itself, a ring chassis has been designed, which was positioned outside the reactor pressure vessel. A servo-electric driven carriage allows 370° rotation in circumferential direction and delivers horizontal and vertical cuts. The mechanical components are laid-out to operate unaffected by the presence of abrasive. The same position sensor as mentioned for the Linear Manipulation System is an integrated component to the Control Unit. It reports the current location of the cutting nozzle.

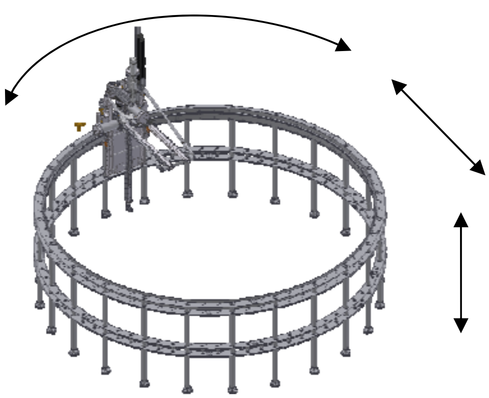


Figure 10: Ring chassis
- 3-axis servo electric manipulator, max. traversing path: x = 800 mm, z = 800 mm, rotation r = 370°, nozzle rotation = 370°

4.6.4. Control of the Manipulation Systems

WAS cuts as described before are conducted under water in water depths of few meters up to 18 m. Due to the presence of radiation in most cases a direct view of the operator to the cutting nozzle and the object to be cut is not permitted. In bigger depths a direct view is not feasible due to distortions generated by turbulences of the water surface and the bare distance. For these reasons the cuts are observed from different angles by several cameras.

The two manipulation systems mentioned before are controlled by a single customized PLC-based 4-axis servo-control unit. Through a touch-screen of a mobile control panel the operator communicates the commands to the servo-control.

Prior to an actual WAS cut a reference-run is conducted. The reference-run is recorded and saved (so called teaching process). The recorded profiles can be utilized in future cutting tasks of the same kind. Reproducible cutting profiles offer the benefit of reduced set-up times.

During reference-runs and actual cuts the mobile control panel reports the direction of movement, traversing speed and actual position of the cutting nozzle. Together with the life-stream images of the cameras the operator has full control of the WAS cuts.
Confirmation that the corresponding section is completely cut through is generally realized by visual means. In case of non-sufficient view (e.g. caused by narrow space) to the section to be cut an under-water acoustic sensors (hydrophone) is the mean to confirm that the cut is completed.

4.7. Water Treatment System

As mentioned in the paragraph before, the cuts of the internals of the reactor pressure vessel are controlled by a camera. To achieve always acceptable quality of the life-stream images, the water has to be effectively cleaned during the cutting process. For this purpose a dedicated water treatment system is positioned in the controlled area of the NPP.
Besides allowing clear view to the cutting area, a second function of the water treatment system is the separation of the higher radioactive contaminated cut material and fine abrasive particles - both amounting for approx. 3% of the total so called secondary waste - from the larger amount of lower radioactive contaminated abrasive. As the latter material can be deposited for significantly lower charges, economical benefits in the same proportion can be realized.

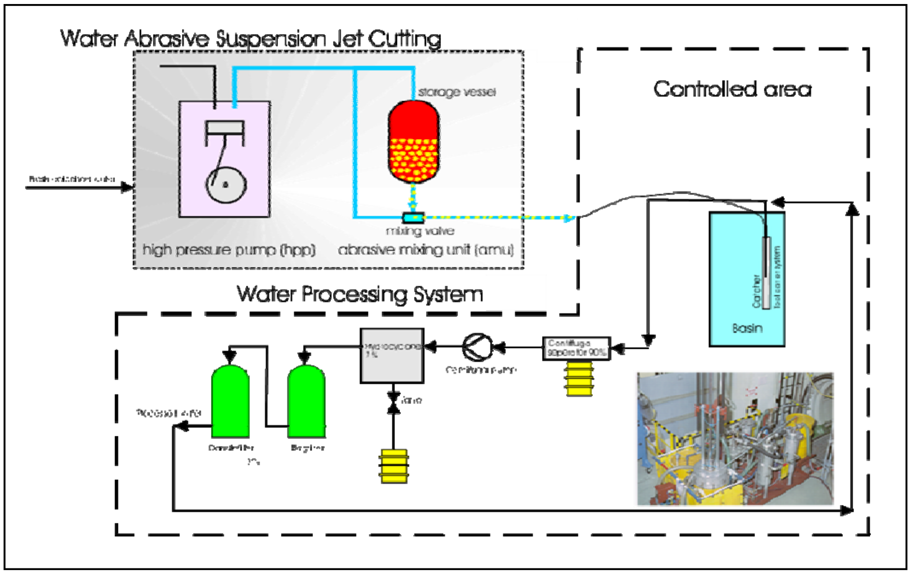


Figure 11: Scheme and image of a water treatment system in a NPP

5. SPECIAL CHALLENGES FOR WATER ABRASIVE SUSPENSION (WAS) JET CUTTING SYSTEMS IN NPPs

5.1. Working with De-Ionized Water

For cutting nozzles used in WAS jet cutting systems Tungsten Carbide is the material of choice as it withstands best the abrasive flow. Tungsten Carbide is a very hard and brittle material, which consists of a high percentage of carbon.

It has been experienced that the lifetime of the cutting nozzle when operating with de-ionized water is significantly lower (15%) compared to known lifetimes when operating with potable water.

Investigations have proven that the de-ionized water's tendency to concentrate elements to the point of saturation dissolves carbon particles from the inner surface of the nozzle, thus making the surface rougher and open for higher abrasion, which results in lower lifetime.

Remedy was realized by enrichment of the de-ionized water with minerals or fresh-water, which improved the lifetime to acceptable 40% of general lifetime.

6. NOMENCLATURE

WAS - Water Abrasive Suspension (WAS) jet cutting
NPP - Nuclear Power Plant
AMU - Abrasive Mixing Unit