Decommissioning Experience at Rokkasho; Standing Type Manipulator: A1000S for Dismantling Tasks – 16434

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ABSTRACT

Decommissioning is a technical process which includes various steps and processes from the clean-up of radioactive materials to the progressive demolition of the plant. One of these steps is the cutting of subassemblies, like tanks, pipes or walls in small pieces suitable for the sorting and disposal. Different solutions are offered for this cutting work and can be grouped as following:

- Chip forming - sawing, drilling, milling, turning etc.
- Shearing - punching, stamping, scissoring.
- Abrading - Grinding, lapping, polishing; water-jet.
- Heat - flame cutting, plasma cutting, laser cutting.
- Electro-Chemical - Etching, Electrical discharge machining (EDM).

Each method has its limitations in accuracy, cost, and effect on the material.

In 2013, Wälischmiller Engineering won a contract for two remote handling systems dedicated to the dismantling cell at Rokkasho Nuclear Fuel Reprocessing Facility in Japan. For this project, Inconel and other metals needed to be cut. One of the main cutting methods was decided to use of an angle grinder handled by a robotic arm.

Because the use of the overhead systems (bridges and cranes) was difficult for this installation, it was determined, that the best alternative was a power manipulator A1000 installed on the floor with a pre-positioning system. The project proceeded to go forward with the adaptation of the standard A1000 with integration of a control system in a Cartesian coordinate frame; resulting in a heavy duty arm; A1000S with 6 degrees of freedom.

The heavy duty power arm A1000S was developed and designed for mechanical cutting with an angle grinder, especially for thick and hard material for example stainless steel and Inconel.

Cutting a thick material with an angle grinder requires repeatable precise linear motion, in order not to damage the disc. The angle grinder should be handled with a manipulator which can cut in all directions in a linear motion, since the objects which should be cut are usually very large and fixed in any direction For these requirements, the Cartesian control function was added to our standard power manipulator type A1000.

In some cases, the decommissioning work includes repeated access routes or fixed access points that the manipulator arm has to pass repeatedly. For example a fixed point where the waste materials are collected, or repeated transport route that the arm has to go along for each step. For this requirement, the A1000S has been equipped with the "GoTo-Mode". It is a "teach and playback mode" which has been developed especially for remote operating manipulators. Quick direct teach, quick play function and an intuitive touch-panel

layout are some of the features. With the GoTo-Mode high working efficiency was achieved.

After rigorous testing at Wälischmiller premises; the manipulator was delivered to JNFL in Rokkasho.
It was found that the obtained functionality and precision can be applicable not only for the cutting with a disc grinder, but also the laser cutting method, which requires precise trajectory control.

This paper will provide

- A project description
- Presentation of solution process
- Technical description of the A1000S
- Future Applications of the robotic Arm A1000S

Development Background: Easy Installation

In 2013, Wälischmiller Engineering won a delivery contract for two remote handling systems dedicated to the dismantling cell at Rokkasho Nuclear Fuel Reprocessing Facility in Japan.

In the decommissioning process, many kinds of remote operated manipulators are used. In order to dismantle large objects or facilities, the manipulators are required to cover a wide working range. For this reason, in some case overhead horizontal and vertical translation systems such as bridge, carriage and telescopic up/down equipment are installed. However, it is very difficult to install such large equipment, especially into existing facilities, in which cells are already radioactively contaminated.

Given these limitations, it was determined a standing floor manipulator was more practical and economical. The cell building would not require modification. Wälischmiller Engineering developed for Rokkasho a floor standing manipulator, which requires only a ridged standing place and a cabling route through a through-wall tube for the cabling. The manipulator is equipped with 4 legs. The standing place is 2.6 m x 2.6 m (8.5x8.5 ft) for covering 4 m (13 ft) horizontal reach and 7 m (23 ft) height working range (see Fig. 3). The number of cables was minimized to 3 cables by applying a signal multiplexer inside the manipulator system.

The installation into the hot cell was done completely by remote handling and successfully finished in a short time.

Requirements to the manipulator

The floor standing manipulator A1000S was developed for the purpose of dismantling large metal equipment in a nuclear facility. The cutting task with angle grinder was specified as a main required task.

In addition to the wide working range, the manipulator had to be robust enough to handle heavy-duty loads and also be equipped with a precise control system. Furthermore, the manipulator must resist against high radiation and metallic dust. Due to the high radiation, direct access for maintenance by humans is impossible. Therefore, remote maintenance and remote rescue are required.

PRESENTATION OF THE SOLUTION; DEFINING THE DIFFERENCES BETWEEN POWER MANIPULATOR A1000 AND ROBOTIC ARM A1000S

Specification of the Robotic Arm A1000S

The solution was to use modules of the A1000 series and to include a robotic function. Regarding the requirements, it was decided to install the arm on a lifting mast, which is placed on the floor. The whole system has been called A1000S on pre-positioning system (PPS). (Fig. 2)

The A1000S has been developed to have six degrees of freedom (6 D.O.F.) (see Fig. 5), making the A1000 a robot with Cartesian control function. It is suitable for installation on a pre-positioning system as shown in the Fig. 2. The A1000S has been designed to work in hostile environments. For that reason it is built of materials, which resist radiation, acids and corrosive substances.

The pre-positioning system (PPS) is composed of four legs and three motion axes (rotation, lift and swing see Fig. 4). With a hoisting system, the ensemble can be pre-positioned inside the cell, allowing a flexible and wide working range. The main mechanical component for the lift axis is a spindle, which requires regular greasing. Due to the inaccessibility by human, an automatic lubrication system was developed and installed. The greasing interval was controlled depending on the running distance and was recorded remotely.
The rotation axis of the PPS has a range of plus / minus 100 degree. The swing axis is an arm extension. Together with the A1000S arm, the manipulator has an operating range of 4 m (13 ft) (see Fig. 1) and a payload of 100 kg (220 lbs). The pre-positioning system is about 4 m (13 ft) high and combined with the A1000S arm they can reach a total height of 7 m (23 ft) (see Fig. 2 and 3).

Fig. 1. Maximum Horizontal Reach: 4 m (13 ft)

Fig. 2. Max. vertical reach of 7 m (23 ft)

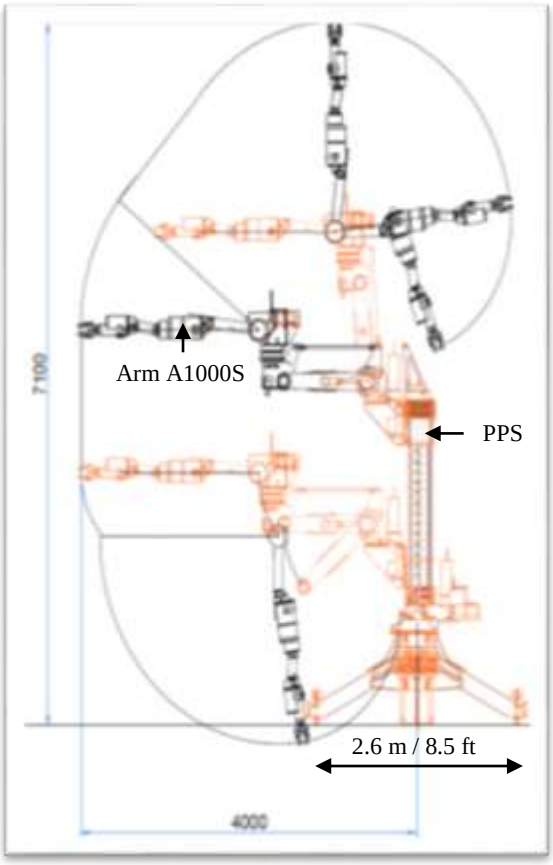

Fig. 3. Dimensions of PPS and A1000S

Fig. 4. PPS Axes

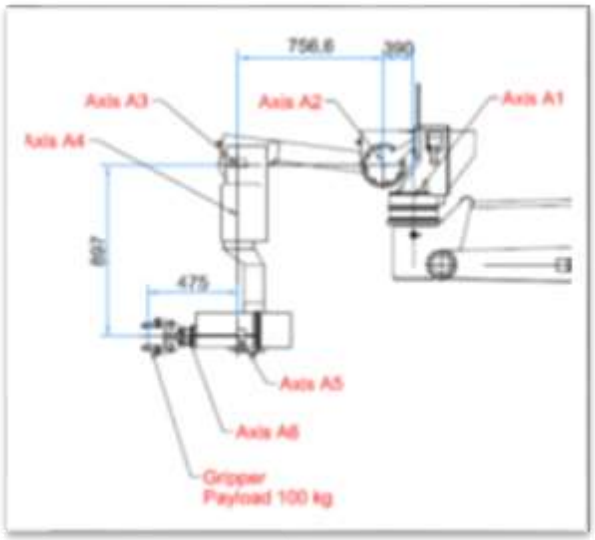

Fig. 5 Arm Axes and Dimensions

Differences between Power Manipulator A1000 and Robotic Arm A1000S

TABLE I. Differences between A1000 and A1000S

Characteristics	A1000	A1000S
Degrees of Freedom	5	6
Payload	100 kg to 200 kg (220 lbs to 440 lbs) Optional 500 kg(1100 lbs)	100 kg (220 lbs)
Robust	x	x
Multi-turn axis	x	x
Remote exchangeability	x	x
External mechanical emergency drives	all joints	all joints
Robot and tool Cartesian coordinate control function	-	x
Teach and play-back control system	-	x

The paragraph above points out the general aspect of the A1000S on the PPS and the main differences with the A1000.

The following paragraph presents the technical aspects of the A1000S more in detail.

TABLE II. Technical Description of the A1000S

Product Type		A1000S - A14108	
Motion Axis Type		Articulated	
Axes		6 joint axes + 1 tool axis	
DOF (Degree of Freedom)		6 DOF	
Max Reach (J1 to Gripper Center)		2,5 m (8 fts)	
Max. Payload		100 kg (220 lbs)	
Drive System		DC Servo Motor	
Max. Working range / max. Speed			
	J1 axis	±135 deg	3 deg/s
	J2 axis	-98 ~172 deg	3 deg/s
	J3 axis	±135 deg	3.6 deg/s
	J4 axis	∞ deg	12 deg/s
	J5 axis	∞ deg	12 deg/s
	J6 axis	∞ deg	22 deg/s
	Gripper	6 in	0.5 in/s
Arm Weight		260 kg (573 lbs)	

Tool Power Supply	AC 200V 12 A
Control	Joint speed control Joint position control 6 D.O.F. Cartesian base/tool coordinate control GoTo-Mode - quick teach and play mode Force limitation Collision detection with 3D simulator
Emergency Rescue System	Rescue external drive for all axes Remote exchangeability for gripper, lower arm unit, upper arm unit, shoulder unit, motor drive unit for PPS, greasing cartouche Remote exchange stand is provided.

Concretely, these technical data point out the 6 D.O.F. of the A1000S. Consequently the materials or facilities, which have to be decommissioned, can be reached from different directions in order to get the best cutting position.

Operation System

The operation system is one of the most important components in the concept of the robotic arm A1000S and made the biggest difference with the standard power manipulator A1000. The A1000S is equipped with:

- Joint speed and position control
- 6 D.O.F. Cartesian base/tool coordinate control
- GoTo-Mode - quick teach and play mode
- Force limitation
- 3D simulation and collision detection

The manipulator is controlled via an operating panel, a touch screen and a 3-D monitoring system. The movements are controlled with levers and pushbuttons (Fig. 9).

SPECIAL FUNCTION S OF ROBOTIC ARM A1000S

Cutting Function with an Angle Grinder

The large objects to dismantle by cutting are fixed, and the cutting line is not simply vertical or horizontal. Therefore, one requirement was that the cutting line has to be in any direction. Tests with Inconel were performed to validate the requirement concerning the linear cutting with an angle grinder (Fig. 7).
The 6 D.O.F. of the A1000S manipulator with Cartesian control made it possible to cut in any direction. Also, the user interface was a very important aspect to reduce the operators stress.
Especially in case of a deep cut, the cutting trajectory was repeated on the same line precisely otherwise the disc would break. No major damages on the disc or on the grinder happened.

The software was designed so that the cutting mode Cartesian coordinate frame is quickly defined by the operator through the touch panel operation. Consequently,

the operator can operate simply 2 levers (for the necessary dimension X: cutting direction, Z: cutting depth) to get the precise cutting result without stress (Fig.6).

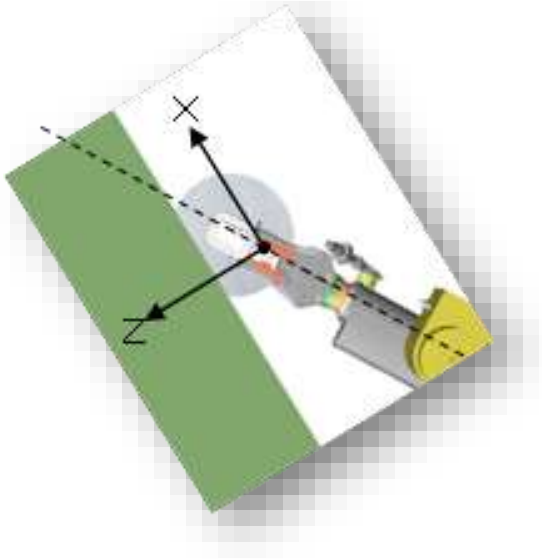

Fig. 6. X: cutting direction, Z: cutting depthFig. 7. Cutting with angle grinder

Fig. 8. Coordinated works with two A1000S

The GoTo-Mode

The A1000S system establishes a user friendly control system including the GoTo-Mode. The GoTo-Mode is an in-house development of Wälischmiller Engineering. It is a teaching and playback system, especially designed for remote controlled manipulators. The unique feature of the GoTo-Mode is the quick-teaching function, and human interactive playback function. During the playback operation, the operator always remains in control. Thus, the automatic mode is very flexible. The operator can adjust the trajectory speed, direction and points at any time during the movement.

During the tests, the GoTo-Mode improved the working efficiency in the complex environment. In a typical case, the hand of the manipulator had to reach through the complex piping objects or through holes, the path points can be taught, so that the backward path or the next path will be simply repeated by single lever.

Fig. 9. Control Panel of the A1000S and PPS

Safety and Recovery, Collision Avoidance

The recovery of a manipulator in case of failure is an important feature like the exchangeability, which has to be provided. Therefore, the A1000S is equipped with external mechanical emergency drives for each joints, including opening and closing the gripper. (Fig. 10) In case of failure of one joint's drive unit, the arm can be lowered, in order to put down the load. The emergency drives can be rotated by using a separate tool. External mechanical emergency drives enhance the operational safety of the arm. The tests proved that the emergency drives fulfilled the requirements. In case of a failure it is possible to replace the defect arm part remotely.

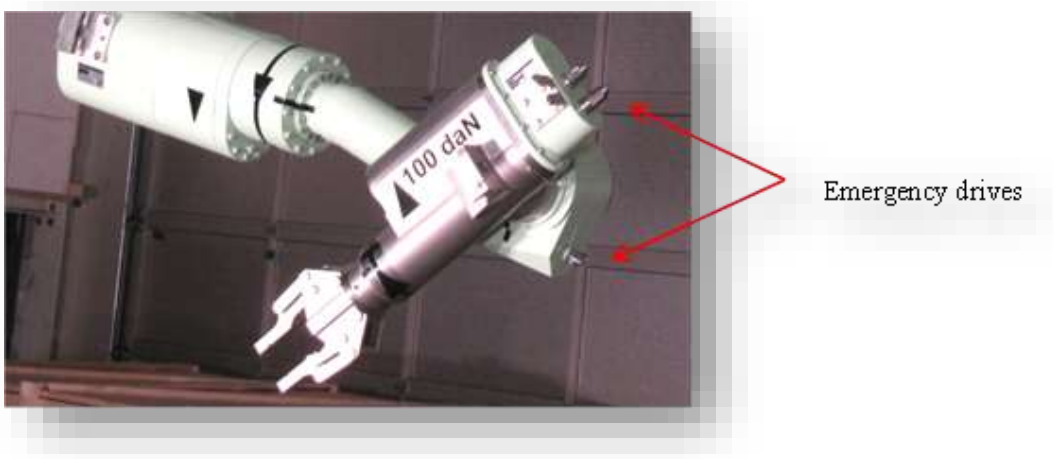

Fig. 10. Emergency drives

The robotic function of the A1000S made also possible for real-time monitoring and collision detection by 3-D-simulation (Fig. 11).

The detailed structure of the manipulator and the environment of the dedicated facility were modelled and simulated in real time. The collision detection by 3D-simulation avoids damages on the manipulator and on equipment placed in the hot cell. The collision detector sends the signal to stop the arm before collision occurs. This function was tested in detail at premises and directly in the facility. The tests demonstrated that the function is more than useful because it avoided damage on the arm and in the facility. On the other hand, the operators feel more confident by using the A1000S and improved the safety of work.

The advantage of the 3-D modelling was also the possibility to simulate the operation in virtual reality to prepare and validate the works, before execution. The working phases could be prepared and then be executed with a higher safety. The coordination of the different remote-handling equipment was easier. (see also Fig. 8)

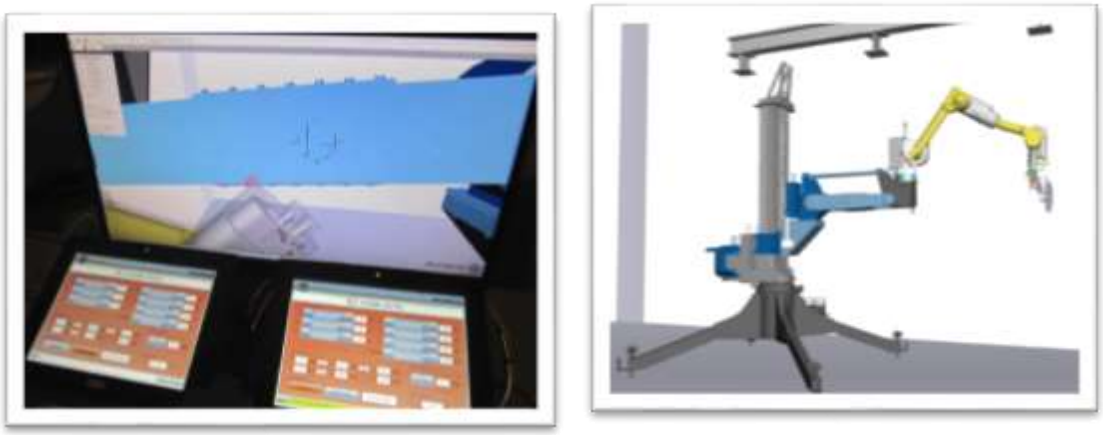

Fig. 11. Collision detection by 3-D-simulation

Exchangeability

An important feature of manipulators in the nuclear industry is to be maintenance friendly. In lot of cells a direct repair on the arm is complicated, expensive and sometimes impossible. In case of failure the parts have to be removable easily and in one piece. It is what we call exchangeability. This feature was important for the customer. A replacement of one part should be done quickly. As shown on the Fig. 12, the arm A1000S and the PPS are composed of single components. As a manipulator issued from the A1000 series, all the arm parts are remotely exchangeable. Only one screw has to be removed to detach the arm parts. The system delivered for Rokkasho included an exchange rack. It means that the arm will be driven in the rack and the parts will be removed remotely and easily from there. The exchange tests and procedures demonstrated the effectiveness of this rack.

Also some components of the PPS are easily exchangeable. For the purpose of decontamination, the bellows type cover of the PPS is easily removable and exchangeable.

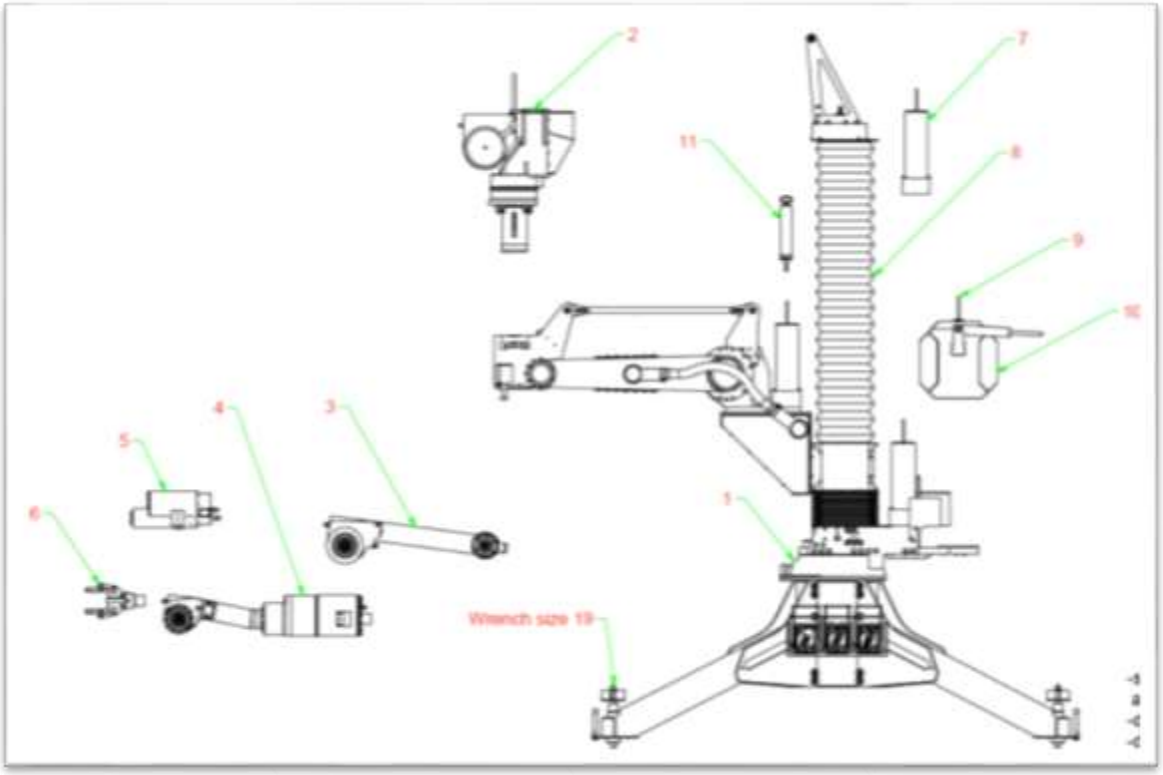

Fig. 12. Arm Units are Parts of the Exchangeability Concept

TABLE III. List of the Remotely Exchangeable Components as Drawn in Fig. 12

Number in Figure 4	**Designation**
1	Pre-Positioning system, standalone system
2	Shoulder of A1000S
3 to 6	Arm elements of A1000S
7	Motor Drive Unit
8	Remotely removable bellows type cover
9 and 10	Signal Multiplexer and Counter Weight
11	Greasing cartouche

CONCLUSION: FUTURE APPLICATION OF THE ROBOTIC ARM A1000S & HOW CUSTOMER NEEDS WILL DRIVE THE NEXT INNOVATIONS IN REMOTE HANDLING & ROBOTICS

As shown throughout this paper, the specific needs of a project require us to rethink the potential applications of our remote and robotic systems. We are keen to adapt our systems to meet the unique needs of each client and each project. It can be seen in the Rokkasho project that we used our technical imaginations to "teach an old manipulator new tricks".

We see a great future for the A1000S and are already considering it for;

- modular system are required to create customized solutions
- telescopic mast, prepositioning system, gantry system as PPS
- position and guide tools, mechanical cutting, thermal cutting, laser torch
- automatic mode, robotic functions
- waterproof, under water decommissioning
- use of a sensor to implement a force feedback information to the operator

We also see this adaptation of a standard piece of Wälischmiller hardware to meet a very specific need of a customer with limited physical options as an example of most projects going forward.

More than ever, the budgets available to solve huge remote handling challenges like the Hanford and Savannah River Tanks and the Sellafield Ponds & Silos are constrained. By developing technology which allows a vendor to use existing standard design which we can adapt and improve; or refurbish an older remote handling system for a new task; our client achieves great cost and time savings on their project; it is a game changer.

In addition, the need to adapt and adopt our systems to our customers' needs forces us to expand the current markets for our innovations beyond the nuclear arena. An example is our development of a version of our radiation hardened TELBOT® robot to meet a specific necessity of the offshore oil and gas industry. The TELBOT®, which has been delivered, is the only worldwide robot which is certified ATEX category 1 zone 0. The robot is equipped with a camera for inspection and a high pressure wash lance. The wash lance is installed in the arm parts. It means that no wiring or water tubes are outside of the arm. The TELBOT® will achieve tank inspection and cleaning. This task has to be performed remotely and given the explosive environment, our TELBOT® had to function in a whole new way. Projects like this drive us far from our nuclear roots, but clearly show the technical adaptability of a sophisticated machine moving from one hazardous environment to another.

But our real near-term challenges lie in the places we know best. The easy part of decommissioning the WWII weapons complex has been nearly completed; Places like Hanford, Oak Ridge, Savannah River and Los Alamos and at sites across the UK and Europe. Lots of buildings knocked down and percent wise, great strides. But what is left is the hard part; many very difficult remediation challenges that will require the next generation of remote handling and robotics to achieve success.

REFERENCES

Technical Description
Technical description of the robotic arm A1000S
User manual of the robotic arm A1000S

Return on experience at Wälischmiller Engineering premises and at JNFL

ACKNOWLEDGEMENT

With the friendly support of JNFL