HANDLING, DISMANTLING AND DISPOSAL CONCEPT OF THE IRRADIATED MEGAPIE LIQUID METAL TARGET

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In 2006 the solid state target of the spallation neutron source SINQ was replaced by the liquid metal target MEGAPIE. In total the lead bismuth target was in operation for 120 days. Currently the target is stored in the target storage facility at SINQ. It is foreseen that next year MEGAPIE will be transported from PSI to the hot cells of ZWILAG (Swiss central interim storage facility) for inspection and dismantling as well as sample taking and preparation for final disposal. The target will be cut into pieces which then can be packed into a waste container. Samples will be taken for the investigation of material properties and the behavior of structural materials in the high radiation field of a liquid metal target. We will present an overview of the main handling steps and discuss the methods that are going to be used for the dismantling and final conditioning of the target.

I. INTRODUCTION

Since 1997 the spallation neutron source SINQ [1] is in operation at PSI. Protons with energy of 575 MeV and a current of up to 1.4 mA are guided vertically upwards onto a solid spallation target – see Figure 1. Several different targets have been used for neutron production up to now. The first targets were fabricated from solid Zircaloy rods, followed by a steel clad lead target, called Cannelloni target. The targets are operated for two years and are then replaced. In 2006 the MEGAPIE target was used for neutron production, followed by the current target, a Zircaloy clad Cannelloni target.

Spallation neutrons are thermalized in an ambient temperature D_2O moderator tank with a diameter of approximately 2 m. A fraction of these thermal neutrons enters the cold source of SINQ, a 20 liter aluminum tank filled with liquid D_2 at 25 K. The thermalized and cold neutrons are guided to the experiments via beam tubes; some of those are equipped with neutron guides.

Within the framework of an international collaboration on accelerator driven systems (ADS), the solid state target of SINQ was replaced by a liquid metal target – a lead bismuth eutectic (LBE) – for a prototype experiment called MEGAPIE (Megawatt Pilot Experiment [2]).

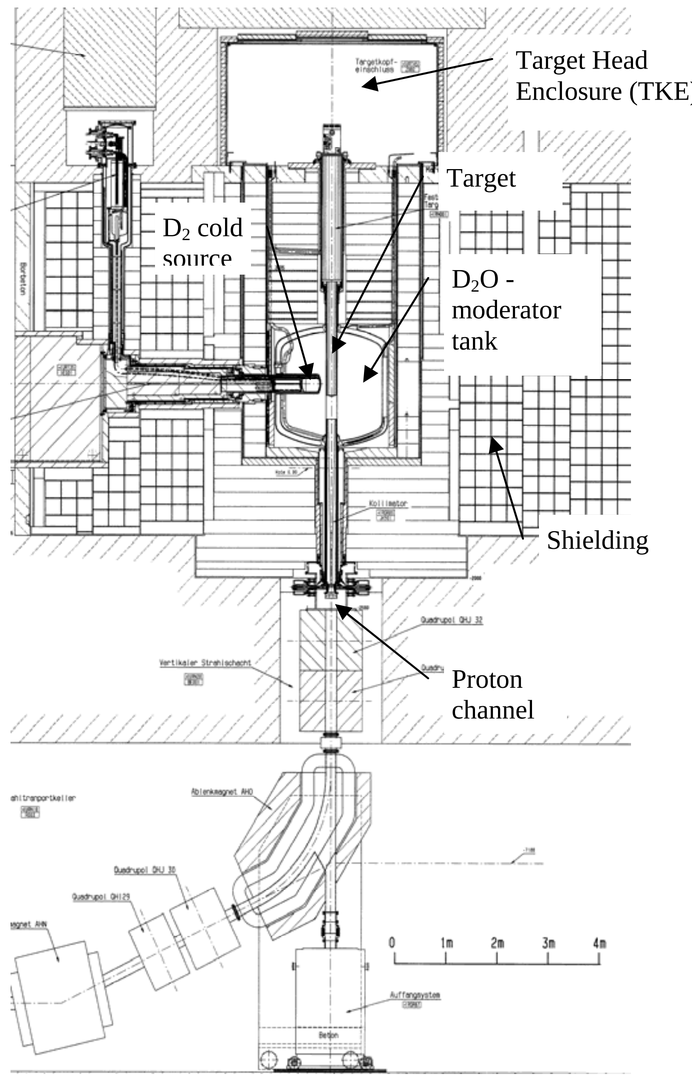

Figure 1: The SINQ facility.

The aim was to study the fabrication and operability of a LBE target. Moreover, the behavior of the structural materials under megawatt beam conditions is of special interest.

The operation of the MEGAPIE target started on 14th August 2006 with a constant beam of 40 μA. Full power was reached on the 21st of August and operation with a stable 1300 μA proton beam continued until December 21st 2006. Overall MEGAPIE received a total proton charge of 2.8 Ah. For more details in the operation and neutronic performance of the target see Ref. [3] and [4].

This contribution describes the handling, dismantling and conditioning of the irradiated and thus activated MEGAPIE target. First a short description of the liquid metal target will be given. Then results of calculations performed for the activation of the target will be presented, followed by a description of the different handling steps needed to dismantle and dispose the irradiated LBE target. A more extensive description of the handling steps can be found in Ref. [5]. Finally a status on the testing of already built facilities and devices for the dismantling will be given.

II. THE MEGAPIE TARGET

The MEGAPIE target consists of two parts containing about 90 liters of liquid lead bismuth eutectic (LBE), see Figure 2.

The lower / upstream part of the target is the interaction zone where the LBE is enclosed by a hull made of martensitic steel (T91) and for safety reasons by a second enclosure made of aluminum alloy (AlMg3). The double walled aluminum container is actively cooled with heavy water. The upper / downstream part mainly consists of steel (90 %) for shielding purposes and houses the heat exchange (oil circuit), cover gas system, and the pumping systems of the LBE.

A compilation of all materials used and the corresponding masses can be found in Table 1.

Table 1: Compilation of materials and masses used in the MEGAPIE target.

Material	Mass [kg]
AlMg3	45
Stainless 316 L	1568
T91	39
Cu	20
Normal Steel	34
Densimet	79
Ceramics	4
Quartz	3
Compound	15
LBE	940

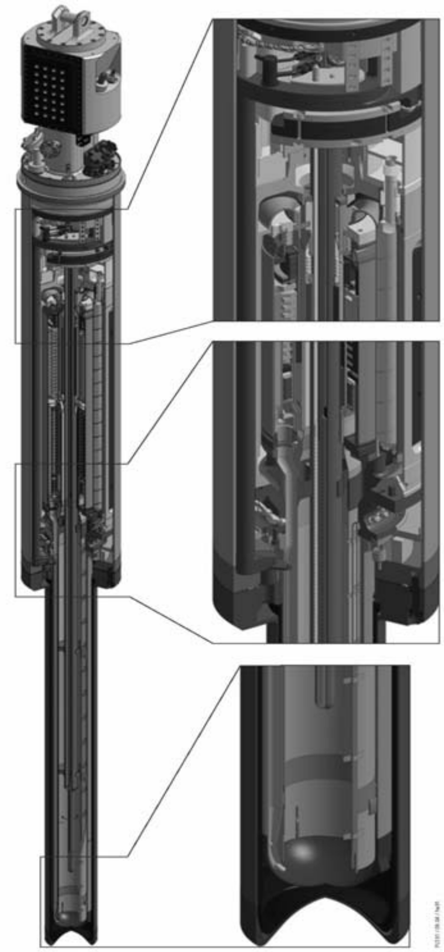

Figure 2: Sketch of the MEGAPIE Target.

III. ACTIVATION CALCULATIONS AND NUCLIDE INVENTORY

The MEGAPIE target was activated in a mixed radiation field consisting of protons, fast and thermal neutrons as well as pions.

The nuclide inventory for the different components of the target has been calculated using the particle transport code FLUKA [6]. In order to estimate the buildup and decay of nuclides, FLUKA was coupled to ORIHET [7]. Details on the calculation of the total nuclide inventory can be found in [8]. The largest amount of activity in the target is located in the 90 liters of LBE. Since the LBE is circulated, this activity is assumed to be homogenously distributed. For the structural materials a dependence of the activity on the location of the material is found. Materials located in the lower part of the target show higher activities than parts from the upper region.

The total activity of the target as a function of cooling time is depicted in Figure 3.

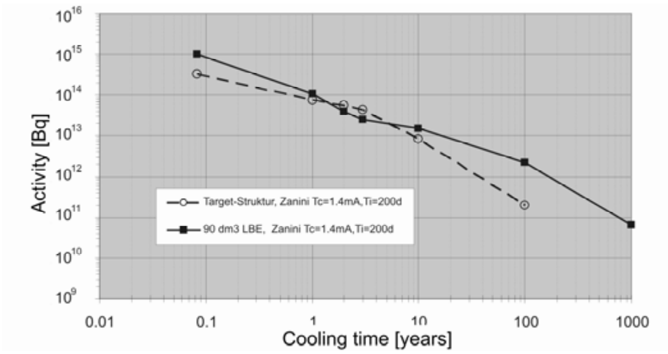

Figure 3: Activity of structural materials (dashed line) and LBE (full line) as a function of cooling time. The data have been taken from Ref. [8].

The dimensioning and design of shielding for the different types of containers needed for the dismantling process have been done with Microshield [9]. The basis for the calculations always was the nuclide inventory as given in [8]. The inventory was calculated for a maximal irradiation period of 200 days with a current of 1.4 mA, corresponding to 6.7 Ah.

IV. THE CONCEPT FOR DISMANTLING AND DISPOSAL OF THE MEGAPIE TARGET

The concept presented here was worked out in close cooperation with the personnel of the involved plants. It is judged as the optimal solution for the disposal, after the evaluation of different operational scenarios. The main work steps are the following:

1. Dismount and transfer the target from the irradiation position to the target storage site at SINQ.
2. Transport the MEGAPIE target to the interim storage site ZWILAG.
3. Inspection and dismantling of the target in the hot cell of ZWILAG.
4. Packing of the dismantled target into a waste container at ZWILAG.
5. Transport of samples to the hot cell of PSI East.
6. Activities in the hot lab.

The last two points, the transport of samples to the PSI hot cell and the post irradiation examination (PIE), will not be discussed in this paper.

IV.A. Target transfer in the SINQ hall

After the irradiation period from August to December 2006 the MEGAPIE target stayed in the irradiation position for 50 days. During this time the LBE was solidified under controlled conditions. In addition short lived radioisotopes decayed.

The decay heat after 30 days is calculated to be 300 W. Spontaneous melting of the LBE during subsequent handling was therefore ruled out (the melting temperature of LBE is 123 °C).

All cooling circuits and the cover gas system were drained, rinsed and dried. All connections of the target to the supportive systems were removed. The exchange flask mounting needed for the transfer was installed in the target head enclosure (TKE) and on the target storage site (TL).

The transfer of the MEGAPIE target from the target block to the target storage site was done with the SINQ exchange flask for standard SINQ targets, see Figure 4.

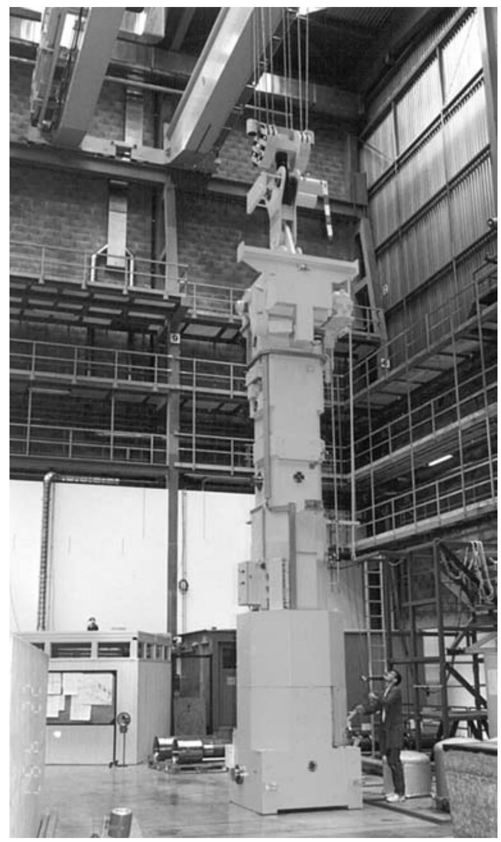

Figure 4: The SINQ target exchange flask.

The procedure was the same as if a solid target would have be transferred. After the transfer, all mountings and supportive structures were removed. The MEGAPIE target currently stays, actively cooled, in the TL. The transport to the central interim storage facility (ZWILAG) is planned for August 2008.

IV.B. Transport to ZWILAG

Although a hot cell exists at the accelerator facilities of PSI it is not possible, for operational and radiological reasons, to dismantle the MEGAPIE target on site. Therefore, the target has to be transported to the hot cell of the central interim storage facility ZWILAG using a specially designed steel container (TC1), see Figure 5.

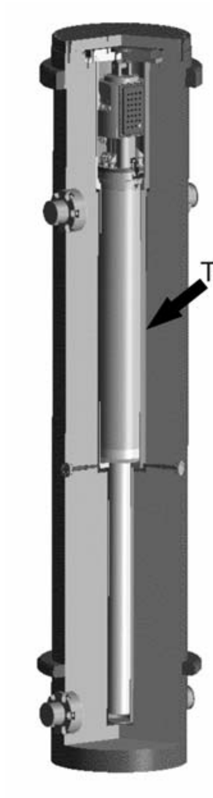

Figure 5: Conceptual design of the transport container. (TC1).

This container consists of 2 main parts. The inner part of the container serves as an enclosure of possible contamination and the outer part is shielding. The container is designed to directly connect to the hot cell at ZWILAG as well as to the target exchange flask. The TC1 is currently fabricated by SKODA in the Czech Republic and is planned to arrive at PSI at the beginning of 2008.

Using the SINQ exchange flask the MEGAPIE target will be moved from the TL into the transport container. The transport container (TC1) will then be lifted on a special transport vehicle and transported to ZWILAG (in a horizontal position). The vehicle will pass over the Aare Bridge, driving on a public road for approximately 1 km before the site of ZWILAG is reached. Therefore, the transport is subject to the regulations for the transport of radioactive materials ADR/SDR class 7 [10]. ZWILAG takes on the role of the carrier and will do the quality assurance for this transport.

The A2-Index of the calculated nuclide inventory is approximately 3000, so that a certified type B container would be required for the transport. However, PSI will apply for a transport under special arrangement at the Swiss Federal Nuclear Safety Inspectorate (HSK) accordant to chapter 1.7.4 in the ADR. The application will describe measures to be taken as a compensation for the specifications of the ADR/SDR that are not met. These concern in particular the integrity of the transport container after a drop from 9 m height, a water immersion check, and a heating test. In addition, due to the high risk potential of the MEGAPIE target a safeguarding plan will be prepared by PSI.

IV.C. Inspection and dismantling at the ZWILAG hot cell

As the TC1 arrives at ZWILAG it be straightened up and subsequently docked to one of the locks of the ZWILAG hot cell, see Figure 6.

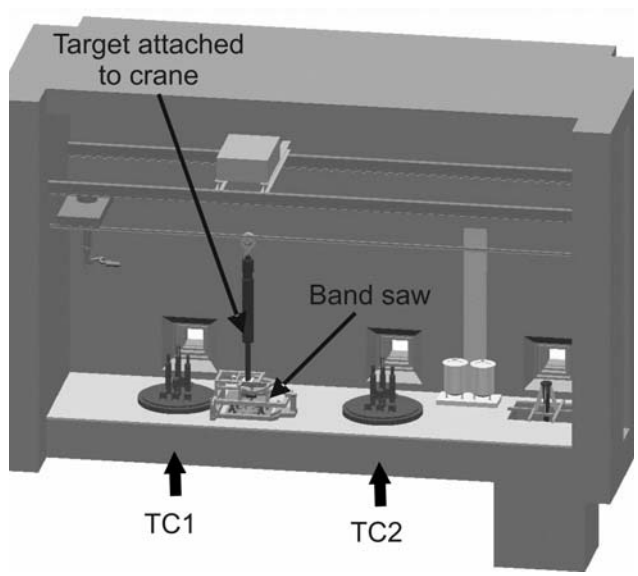

Figure 6: Hot cell of ZWILAG. The target is brought in with the TC1 container, waste will be filled in primary containers and packed into the waste container TC2.

The MEGAPIE target will then be pulled into the hot cell with the crane. The target is placed in a special rack and the aluminum hull is screwed off the target.

A visual inspection of the target will follow. Then the beam window section of the T91 steel will be measured, to investigate the macroscopic behavior of the irradiated steel container.

Subsequently the target is lifted in a special separator equipped with a band saw and cut piece by piece from the bottom up, see Figure 7.

The sawing of the MEGAPIE target will be done without any cooling. Splinters are going to be collected with a suction system. The cutting positions for the 19 pieces are shown in Figure 7.

The pieces number 1, 2, 3, 5, 13, 15 and 17 will be used as samples for further investigation and therefore will be shipped to the hot cell on the east side of PSI. This transport will be done with an already existing container from PSI.

The target is cut into 7 pieces until the flange of the aluminum hull is reached. Then the hull is attached again to the target and cutting is continued.

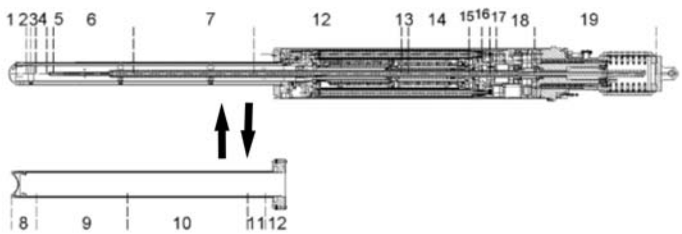

Figure 7: Anticipated cutting positions of the MEGAPIE target.

IV.D. Packing of the cut MEGAPIE target

The cut target sections are cleaned and packed as tight as possible into primary containers – see Figure 8.

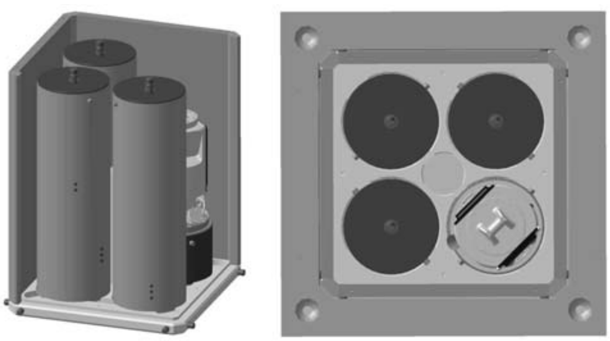

Figure 8: Left: Primary containers with pieces of the MEGAPIE target. Right: Reinforced standard PSI concrete waste container (type KC-T12) filled with primary containers.

These primary containers consist of steel, have a cylindrical shape and possess reinforced shielding if necessary. Containers that are filled with aluminum or parts that had contact to LBE will be closed with a lid that is then remotely welded on the container. This inhibits the production of hydrogen due to contact of aluminum with concrete. In addition a spread of α – contamination is ruled out. The primary containers will be packed into a reinforced standard PSI concrete waste container (type KC-T12). The waste container (TC2) is located at the second lock of the hot cell in ZWILAG (see Figure 6). It is closed with a lid and brought to the "Umladebucht".

To avoid interim storage of the raw waste, PSI is aiming for the permission to condition the waste to be available at that time.

At the "Umladebucht" the container can remotely be filled with concrete and the lid will be sealed. The conditioned container will reach the IP2 limit for the transport about 2 to 3 years after end of irradiation.

It is intended to store the container for a few years in the storage area for medium active waste (MAA) at ZWILAG. An immediate transport of the waste to the Swiss interim storage facility for waste from medicine, industry and research BZL), located at PSI, is not possible because of the high risk potential of the container.

According to recent calculations of dose rates to the public after a plane crash, storage in BZL would be possible 4-5 years after end of irradiation, see Ref. [11].

V. TESTING OF TOOLS AND DEVICES

A campaign to test the different procedures and tools for the dismantling and disposal of the MEGAPIE target took place in January and February 2007. The main focus during the tests was to investigate the behavior of the sawing device as well as supportive tools under real conditions in the ZWILAG hot cell. Essentially the whole cutting and handling procedure that is planned for 2008 was run through (see Figure 9 - 12).

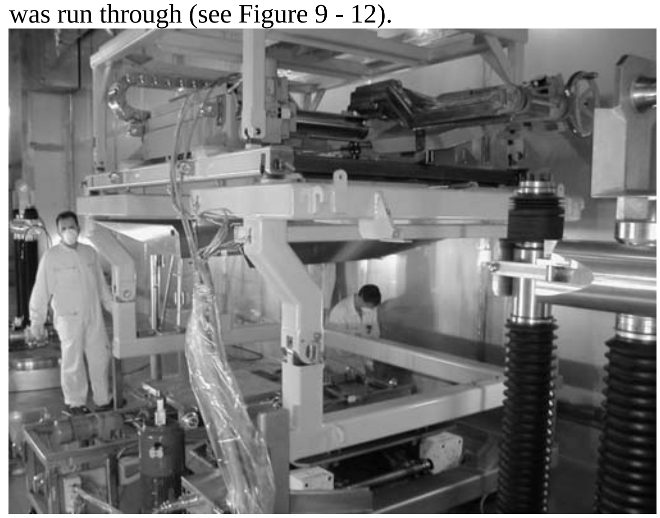

Figure 9: Installation of the sawing device to cut the MEGAPIE target in the ZWILAG hot cell.

Several scenarios and handling steps were studied:

1. Installation of the sawing device in the hot cell (see Figure 9)
2. Handling of the target in the hot cell
3. Testing of the sawing device; simulation of cutting, exchange of the blade.
4. Handling of cut target pieces; placement in the primary containers.

5. Manipulation of primary containers; welding, lifting with the crane.
6. Unmounting and decontamination of the sawing device.

In the first days of the campaign the accessibility of crucial parts of the cutting device and of all tools with the power manipulator and crane was checked - see Figure 10.

The finding was that due to the limited space available in the hot cell the correct positioning of the crane and power manipulator is important as they might block each other.

In a second phase the handling of the target in the hot cell was practiced with a dummy target. The dismantling of the aluminum hull from the target was successful and the target was stored in the waiting position – see Figure 11. This was followed by tests of the saw to cut the target. First simulations of the target cutting in the upper target section were performed. The aluminum hull was screwed back on its flange and the cutting of the target up to the flange of the aluminum hull was tested. The positioning and holding mechanism of the sawing device worked well.

Subsequently the transfer of a cut piece from the saw to a primary containers and the welding of the primary container was also practiced successfully. Docking tools installed on the crane for the transfer of the welded primary containers to the TC2 worked as anticipated.

Figure 10: Access tests in the ZWILAG hot cell with the power manipulator.

One phase of the test campaign in the ZWILAG hot cell was dedicated to practice procedures in the event of certain failures of devices. One of the major incidents that could happen during the cutting of the target is that the band of the saw gets stuck or breaks. In this case the blade has to be replaced. This procedure was dry tested.

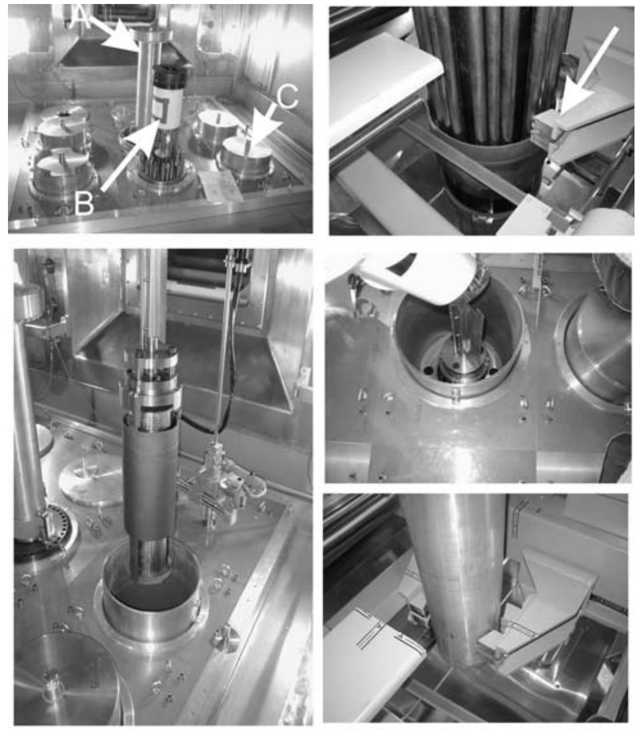

Figure 11: Photos from the cutting tests of the target. In the upper left picture the unscrewed aluminum container (A), the target in waiting position (B) and the primary containers (C) are depicted. The upper right picture shows the simulation of a cut in the upper part of the target; the arrow indicates the holding mechanism. In the lower left and middle right picture tests of the handling of the cut target piece are shown. The lower right picture shows the aluminum hull screwed on the target positioned in the sawing device.

A wire cutter was fed into the hot cell and the band was cut using the tool with the power manipulator. Subsequently the saw was brought into a separate shielded compartment of the hot cell where the new blade for the saw was installed - see Figure 12.

The final phase of the testing campaign in January this year was dedicated to the transfer out of the hot cell and decontamination of the used tools. A milestone was to dismantle and transfer of the sawing device out of the hot cell. One of the concerns here is not to have too high contamination. Therefore the saw will be cleaned as good as possible using a vacuum cleaner before being transfered out of the hot cell. It was found that this procedure needs more careful planning.

Figure 12: Replacement of the band saw blade in a shielded compartment of the ZWILAG hot cell.

Another point currently being investigated is the confinement of contamination and the cleaning of the ZWILAG hot cell after the cutting of the MEGAPIE target. An incident with a broken SINQ target rod in the hot cell of PSI West showed that the cleaning is time consuming and leads to rather high dose to the personnel involved. Therefore, it is desirable to avoid or confine the contamination as much as possible. This might lead to some design changes of the sawing device.

VI. OUTLOOK

In August 2007 another testing phase will start that is mainly dedicated to the handling of the TC2. This includes the docking of the concrete container to the ZWILAG hot cell, the positioning of the primary containers in the TC2 and the conditioning of the filled TC2 at the "Umladebucht".

In January 2008 the transport container to ship the MEGAPIE target from the SINQ storage to the ZWILAG hot cell will be delivered from SKODA. It is not yet clear, if the ZWILAG schedule will allow practicing the handling of the TC1 immediately. However, if there is no time frame for the test, the handling steps with the TC1 will be practiced in August 2008.

In August 2008 the period scheduled for the dismantling and disposal of the MEGAPIE target in the ZWILAG hot cell will start. Currently the planning is to finish all dry tests not performed up to this date and then to start the dismantling of the MEGAPIE target as described. In December 2008 the target should be cut, probes should be shipped to the hot cell of PSI and the pouring of the concrete to finalize the disposal should be done. However, if testing of the tools and devices takes too long, the dismantling of the target would be postponed to April 2009.

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