MEGAPIE on the way to PIE

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Abstract. The MEGAPIE target was the first liquid metal target ever operated in the Megawatt regime, at a power level of 0.8 MW. The LBE target has successfully been irradiated in a period from August until December 2006. During this time the spallation target received a beam charge of 2.8 Ah of 590 MeV protons. After the successful operation of the target it has been stored in the target storage facility of PSI, waiting for its post irradiation examination, PIE. In the time since the end of 2006 several campaigns of tests have been conducted by PSI and interim storage facility of Swiss nuclear power plants - ZWILAG - in the hot cells of ZWILAG. In these tests the feasibility of the conditioning of the target and the extraction of sample material for the PIE has been proven. It is planned to start the dismantling of the MEGAPIE target in June 2009. The dismantling campaign will last until the end of 2009. The PIE activities are foreseen to start in late 2009 or early 2010. In this paper we report on the outcome of all cold tests of the dismantling that have been done. In addition a detailed description of the procedure of dismantling and sample taking of MEGAPIE will be given.

1. Introduction

The Swiss spallation neutron source (SINQ) [1] is in operation since 1997. Over these years of operation a steady improvement program for the target system was pursued [2]. Already in 1992 a liquid metal target system was proposed to be operated in SINQ. It took another 14 years before the target system, then called MEGAPIE (Megawatt Pilot Experiment) was put into operation[3]. A lead bismuth eutectic (LBE) was chosen as a target material. MEGAPIE was operated successfully from August until December 21st 2006 and received an overall beam charge of 2.8 Ah of 590 MeV protons. In the shutdown period starting January 1st 2007 the target and its ancillary system were dismantled and the target was transferred to the target storage facility located in the vicinity of the SINQ target block. As MEGAPIE was the first LBE target to be operated in the Megawatt regime (0.8 MW) an extensive post irradiation examination (PIE) program was prepared during and after the irradiation period. Currently the last tests for the PIE of MEGAPIE are on their way and the dismantling, a conceptual description can be found in [4] and [5], of the target shall start on June 15th of 2009. The target will be cut into 21 pieces using a band saw. Due to the α-activity (mainly long lived Polonium isotopes) the cutting of MEGAPIE can not be done in the hot cell located in the accelerator complex of PSI. However, the hot cells in the interim storage facility ZWILAG, located in the direct vicinity of PSI are suitable for this task. Therefore, it was decided that the MEGAPIE target will be cut there. Subsequently the material for sample taking will be shipped back to PSI, while the remaining part of the target will be conditioned and prepared for final storage in the planned final repository for medium active waste in Switzerland. The sample material will be investigated in the Hot Laboratory of PSI. In a first step LBE samples will be taken from the different target pieces. Subsequently the pieces will be heated in a special oven so that the structural materials and the LBE are separated. Thereafter several hundreds of samples for testing the properties of the irradiated structural materials will be

produced. These samples can then be retrieved by the international partners of the MEGAPIE project at PSI.
In this report we will present the status of the MEGAPIE project. In Chapter 2 the procedures for the transfer of the MEGAPIE target from PSI to ZWILAG and the cutting of the target will be explained in detail. Some information on tests done for the different steps will be given. The licensing of the dismantling will be discussed as well. In the subsequent chapter an overview on the planned operations in the Hot Laboratory at PSI will be given, together with a short description of the samples to be produced. Finally the schedule of these operations will be discussed and a short outlook will be given.

2. The transfer of MEGAPIE to ZWILAG and its dismantling

After the end of the operation time of MEGAPIE on 21st of December 2006, the target was transferred from the irradiation position in SINQ to the target storage facility located next to the SINQ target block. This operation was done with the standard SINQ target exchange flask. The mounted exchange flask on the target storage is depicted in **Error! Reference source not found.**. Since then the frozen LBE target is stored there, without any active cooling as the induced afterheat in the target is low.

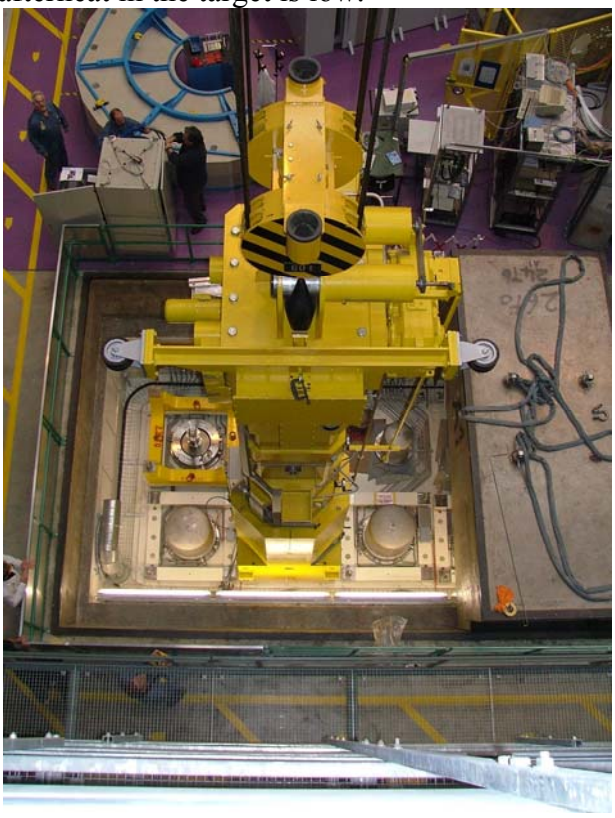

FIG. 1: SINQ target storage facility with mounted exchange flask.

On June 15th 2009 the dismantling phase of the MEGAPIE project will start. Generically speaking this phase can be subdivided into four parts: the transfer of the target from PSI to ZWILAG, the cutting of the target and the conditioning of the unneeded parts, the transfer of the sample target pieces to the hot laboratory at PSI and finally the preparation and investigation of the samples.

2.1. Transfer of the MEGAPIE target from PSI to ZWILAG

As a first step the target will be pulled out of its parking position in the target storage facility with the SINQ target exchange flask. The target will be lifted into a special transport container (TC1) which was manufactured for the transport of MEGAPIE from PSI to ZWILAG. For safety reasons this container is placed in the centre of a cube-like structure made from concrete blocks. This prevents the TC1 from tilting during an earthquake and reduces the dose rate to personal. The primary and secondary lids of the TC1 will be closed and their tightness will be checked. Now one side of the "concrete cube" will be removed so that the TC1 can be moved from its parking position to a special transport vehicle called "Goldhofer", where the TC1 will be brought into a horizontal position for the transfer to ZWILAG. A series of dose rate measurements will be performed on the surface of the TC1 before the actual transfer to ZWILAG will start. The transfer is scheduled for June 24th.
The transfer of the MEGAPIE target from PSI to ZWILAG would fall under the regulations of the ADR, if a public road would be used. However, the factory premises of ZWILAG and PSI are adjoined to each other. As a consequence the ADR is not valid, but PSI has built the transport container TC1 for MEGAPIE such, that it obeys the rules of ADR. Only a few exceptions have been made due to cost reasons. According to the ADR the containers have to be drop-tested and have to withstand a fire over a certain time span. For such tests several TC1 containers must have been built, so that PSI decided in accordance with the Swiss authorities that only theoretical predictions of the damage due to a drop would be made. As the maximum lift height of the TC1 is 2.5 meters the layout was done for this height rather than the requested 8 meters from the ADR. Several additional safety measures will be done for the transfer of the TC1: the transfer will take place at night, the road (which is not public anyway) will b blocked so that no traffic can pass, fire fighters and safety people from PSI will guard the transfer and the vehicle will drive with a maximum speed of 5 km/h.
In order to test the procedures and the transfer a test transfer was performed in January 2008 which was successful. This test as well included the first step of the second part of the dismantling. After the TC1 was shipped to ZWILAG the handling and docking of the container to the hot cell was tested successfully.

2.2. The dismantling of MEGAPIE in the hot cell of ZWILAG

For the later investigation of MEGAPIE it is necessary to cut the interesting parts from the target. This will be done with a band saw, which has extensively been tested in the last two years. As the whole dismantling will take place in a hot cell, the band saw will not be cooled with any liquid in order not to have any activated liquid materials for a later disposal. Within several campaigns in the hot cell of ZWILAG the whole dismantling procedure was cold tested with a dummy target, see *FIG. 2*.
Not only the cutting of the target, but also the cleaning, handling of cut pieces and the preparations for the transfer of the sample pieces to the Hot Laboratory of PSI have been simulated under realistic conditions. During these test phases so called Q-plans have been finalized. These documents describe each of the subtasks of the dismantling of MEGAPIE on a step-by-step basis and will serve as a guideline during the hot dismantling.

FIG. 2: The positioning of dummy target, used during the test campaigns, over the saw.

One of the main problems during the dismantling of the MEGAPIE target is the production of airborne particles leading to contamination of the hot cell of ZWILAG. To minimize the production of such particles, the velocity of the saw blade is limited to 17 m/min, the feed of the blade will be 5 mm/min. This will decrease the probability of melting the LBE during sawing. Locally a melting is possible due to the heating of the blade in structural materials. A quantification of the airborne activity is hard as no tests with activated material where possible. However, measurements during cutting normal LBE revealed a concentration of maximum 170 µg/m3 of aerosols in the direct vicinity of the blade. In addition a suction system is installed roughly 50 cm from the blade, see *FIG. 3*, so that aerosols produced will be directly transferred to the filtering system of the hot cell.

FIG. 3: Suction system in the hot cell, to prevent a spread of contamination.

Over all 20 cuts will be done on the target. In total 9 of theses cuts as well as the so called leak detector will be transfer from ZWILAG to the Hot Laboratory of PSI for further

investigations. The remaining 11 pieces will be put in special steel containers, partly equipped with additional lead shielding. These containers will be closed and welded. The welding procedure has been tested in the last testing campaign lasting from August until December. Detailed investigations of the welding showed, that it is tight and no abnormalities have been found. Overall four of these steel containers will be placed in a standard concrete waste container of PSI, which has been reinforced by a special steel insert, see *FIG. 4*.

FIG. 4: The steel containers with the waste material are placed in a reinforced standard concrete waste container of PSI

After the concrete container is filled, concrete will be placed in the gaps between the steel containers and the waste container will be temporarily placed in ZWILAGs storage facility for medium active waste.

The 9 sample pieces of the MEGAPIE target will be packed in a vessel, which will be placed in a transport container (TC3). This container will be brought to the Hot Laboratory of PSI.

3. The investigations of the sample material at PSI

Nine sample pieces are transferred from ZWILAG to PSI, which cover different parts of the target. Four pieces and the leak detector are from the lower part of the target. They mainly consist of parts of the lower liquid metal target container (LLMC), the riser tube and frozen LBE. One of the pieces is the beam entrance window from the so called safety hull, an Aluminium shell placed around the LLMC. The sample pieces from the upper contain parts of the cover gas system as well as a piece of one of the electromagnetic pumps of MEGAPIE.

In a first step the Aluminium beam window will be investigated to determine the average proton beam footprint on MEGAPIE. These investigations have already been done with the beam entrance windows of several standard targets at PSI. A gamma mapping through a pin hole will reflect to production of ^{22}Na in the Aluminium alloy which is directly proportional to the proton fluence at a certain point.

In the next step LBE samples will be taken from the different parts of the target. These samples will be analysed by gamma spectroscopy. Radiochemical separation will be done to study non-gamma emitting radioisotopes with different techniques. The goal of this study is in first place to create a validation basis for nuclear reaction models used for the design of MEGAPIE. This information is not only of interest for the scientific community, but is also requested by the Swiss authorities in order to review the quality of the theoretical predictions for the declaration of waste from the accelerator facilities at PSI.

After the LBE sample taking the structural material have to be separated from the LBE. This is done by heating the sample pieces in a special oven to a temperature of 200ºC (the LBE melting point is at 123ºC), see *FIG. 5*.

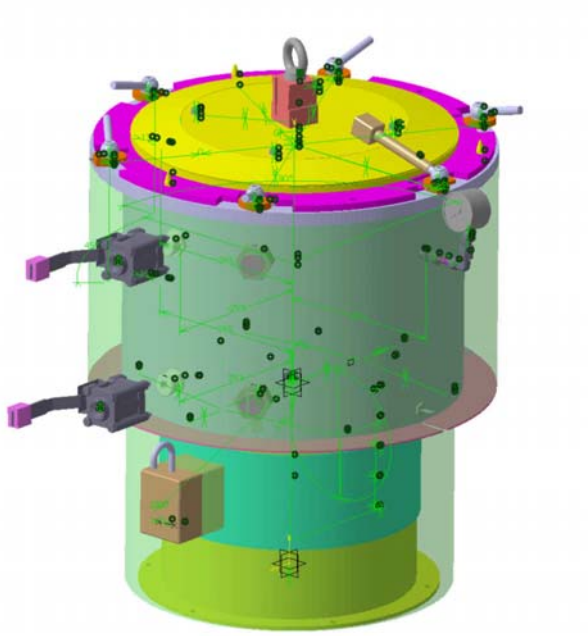

FIG. 5: Oven to melt the LBE in the Hot Laboratory. The sample pieces will be loaded in the upper part and the molten LBE is captured in the lower part of the oven.

The temperature of the sample pieces should on one hand be high enough to melt the LBE, on the other hand with increasing temperature the production of aerosols increases. Therefore, to prevent contamination of the hot cell in the Hot Laboratory the oven is a closed system, which can be vented via a special filter system consisting of a HEPA 16 filter followed by a charcoal filter impregnated with Sulphur and another HEPA 16 filter. Thereafter a cold trap will freeze out any remaining aerosols, before the gas is released to the exhaust system of the hot cell. The design of the oven and filter system are nearly finished and will, after manufacturing, be tested extensively.

The molten LBE is collected in a shielded tank below the oven and will be disposed with the whole oven at the end of the sample taking process. It is expected that a thin layer of LBE will stick on the surface facing the LBE. Therefore, tests have been conducted using specially prepared samples with a layer of ~ 20 µm of LBE on them. They have been cut in the EDM machine, which is going to be used to cut samples from the structural material of MEGAPIE.

Hundreds of samples will be manufactured from the different structural parts of MEGAPIE, according to [6], see *FIG. 6*.

A portion of these samples will be analysed by PSI, while the rest of the sample material is going to be distributed amongst the international partner of the MEGAPIE project. The samples will be prepared at PSI and then be picked-up by the international partner of the MEGAPIE project at PSI.

3. Outlook

The licensing of the whole dismantling and sample taking process of the MEGAPIE target is well on its way. Approvals have been requested for almost all necessary sub steps of the dismantling process, i.e. the transfer of the target from PSI to ZWILAG, the cutting of the

target, the disposal of the waste parts and the transfer of the sample pieces to the Hot Laboratory at PSI. The PIE program in the Hot Laboratory at PSI is currently worked out in detail and shall be sent to the Swiss authorities mid of May.

FIG. 6: Sample extraction layout for the beam entrance region of the beam entrance region of the LLMC.

Currently it is envisioned to start the whole project on June 15th 2009. The transfer of the target from PSI to ZWILAG is planned for June 24th 2009. This will be followed by visual inspections and preparatory work for the cutting of the target. According to the schedule the first cut of the target shall be done July 1st 2009; the last cut is foreseen to be done on August 7th. This phase will be followed by preparations for the transfer of the sample parts and the disposal of the waste pieces of the target. At the end of August it is intended to perform the transfer of the samples to the Hot Laboratory of PSI. In parallel the cleaning of the hot cell and all components used for the dismantling at ZWILAG will start. By the end of 2009 this working steps shall be finished.
First samples for PIE investigations will be ready at the end of the first quarter in 2010.

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