Journal of Nuclear Materials 377 (2008) 12–16

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

MEGAPIE at SINQ – The first liquid metal target driven by a megawatt class proton beam

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A B S T R A C T

The lead–bismuth liquid metal target MEGAPIE (MEGAwatt Pilot Experiment) was operated at the Swiss Spallation Neutron Source SINQ starting mid-August 2006, for a scheduled irradiation period until 21st of December 2006. The continuous (51 MHz) 590 MeV proton beam hitting the target reaches routinely an average current of ~1300 μA, corresponding to a beam power 0.77 MW. This article illustrates the main features of the target and the ancillary systems specially needed for the liquid metal target operation. Further, the operational experiences made with this target during start-up and routine operation are summarized, besides the general performance highlighting new beam and target safety devices, and last but not least the neutronic efficiency in relation to the previously operated solid lead target.

1. Introduction

SINQ, the Swiss spallation neutron source, is driven by PSI's 590 MeV proton accelerator. Receiving a stable proton current of ~1300 μA, SINQ is the presently most powerful accelerator driven facility worldwide. Besides the primary designation of SINQ to serve as user facility for neutron scattering and neutron imaging, PSI seeks to play a leading role in the development of the facility, focusing to spallation targets and materials research for high-dose radiation environments. Serving these activities, SINQ has established several projects, the most prominent one being MEGAPIE (MEGAwatt Pilot Experiment), a joint initiative by six European research institutions (CEN-SCK (B), CEA (F), CNRS (F), ENEA (I), FZK (D), PSI (CH)), the EU, and JAEA (Japan), DOE (USA), and KAERI (Korea) to design, build, operate and explore a liquid lead–bismuth spallation target for 1 MW of beam power [1]. Such a target is under consideration for various concepts of accelerator driven systems (ADS) to be used in transmutation of nuclear waste and other applications worldwide. The goal of this experiment is to explore the conditions under which such a target system can be licensed, to accrue relevant materials data for a design data base for liquid metal targets, to gain experience in operating such a system under realistic beam conditions, and to ascertain the neutronic performance of such a target for the use in SINQ and other (future) accelerator driven neutron sources.

2. The MEGAPIE target

In shape and external dimensions, the MEGAPIE target has to match the given opening in the target block shielding, demanding a slim, about 5 m high structure [2]. In its interior, it is completely different as compared to the normal solid 'lead-cannelloni' target of SINQ (the latter being described in [3,4]): The MEGAPIE target houses about 1 ton of liquid lead bismuth eutectic (LBE, melting point at 125 °C) in a steel container, closed-end by a hemispherical beam window at the bottom. The main features inside are two electromagnetic pumps for forced circulation of the LBE, a flow guide tube inserted into the lower liquid metal container to separate the annular LBE down-flow from the central up-flow, and 12 heat exchanger pins for removing the energy deposited by the beam and/or keeping the target at temperature when the beam is off. Further, the target is equipped with a variety of instrumentation, mostly thermocouples, for operational control, or serving safety features or experimental observation. Fig. 1 shows two of the major target components, i.e., the 12-pin heat exchanger and the central flow guide tube. Fig. 2 shows the fully assembled MEGAPIE target lifted before being inserted into the SINQ operation position.

3. Ancillary systems

The MEGAPIE ancillary systems directly necessary for the target operation are the heat removal system (HRS), the cover gas system (CGS), the insulation gas system (IGS) and the fill and drain system (F&D).

The HRS [5] consists of two subsystems: an intermediate cooling loop with oil Diphyl THT as heat transport medium, connected to the heat exchanger pins in the target, and a back-cooling water loop (WCL). The oil loop, operating between 160 °C and 230 °C, is primarily necessary to remove the about 0.6 MW of heat load deposited in the LBE by the proton beam. As a second function it must also be capable to manage a controlled hot-standby operation

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doi:10.1016/j.jnucmat.2008.02.057

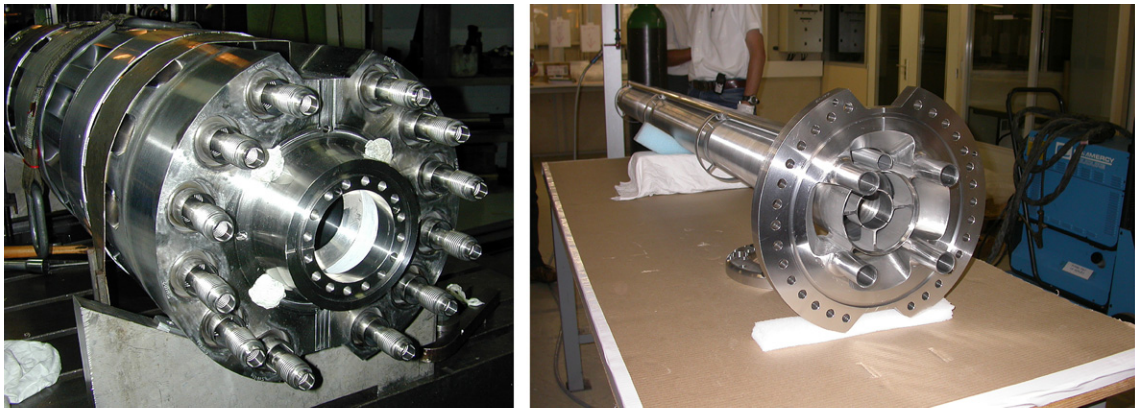

Fig. 1. Two major target components prior to integration: the 12-pin heat exchanger (left) and the central flow guide tube.

Fig. 2. The fully assembled MEGAPIE target before being inserted into the SINQ operation position.

after beam trips or scheduled beam interruptions to prevent freezing of the target.

The CGS [6] must handle the volatile, mostly radioactive inventory of spallation products released from the LBE in the target. Handling of radioactive gases and volatiles imposes stringent requirements on safe and remote operation, on retention of radioactivity, like second containment and tightness, and on shielding.

The insulation gas [7] fills the volume between the inner hot part of the target and the outer cold hull. Besides its function as thermal barrier it must safely cope with the potential incident of cooling water entering the insulation gap and getting into contact with the hot interior of the target.

The F&D system is needed to allow filling and draining of liquid LBE into or out of the target, respectively. Fig. 3 shows a view from above into the target head enclosure chamber TKE (situation of April 2006). The target head is in the centre, still without the cables connected which are in preparation in the rear, the oil loop of the HRS is at the right, the CGS in the left rear corner, and the F&D system at the left.

The initial baseline for the F&D system required draining of activated LBE from the target after the operation period. A detailed design for that was elaborated; however, the draining option was recognised to bear considerable risks, immediate ones, like possible contamination of the TKE, and more general ones related to licensing. Furthermore, it would have required considerable extra expenditure in its technical realization. In view of these difficulties the decision was taken to abandon the initial concept in favour of a draining option only in the non-activated state, prior to irradiation, and final freezing of the LBE in the target after completion of the irradiation experiment [8].

4. MEGAPIE irradiation start-up

The first beam on MEGAPIE was received on August 14, 2006: at a relatively stable and constant beam current of 40 μA, which corresponds to about 25 kW of beam power. The target accumulated a total charge of 60 μA h in this first phase. The second phase of the start-up procedure was successfully accomplished the following day, where the power was stepwise increased to 150 kW (250 μA proton current). The corresponding beam history is shown in Fig. 4. The goal of this phase was to check and verify the response of the heat removal system at power conditions comparable to those used when operated out of beam at the test stand in the autumn of 2005. The third and final phase of the start-up procedure was successfully accomplished on the 17th of August, when the power was stepwise increased to 700 kW (1200 μA proton current). The second graph of Fig. 4 shows the beam history during the ramp-up phase. At each power level the beam was interrupted after some 10 min with a stable proton beam, to verify the predicted temperature transients in the target. Most of the seemingly erratic beam behaviour was thus intentional.

5. New proton beam safety devices

For safe target operation a sufficiently broad footprint of the incident proton beam on the SINQ target is mandatory. If for any reason the protons were not scattered sufficiently in an upstream target (Target E) their footprint on the SINQ target could shrink leading to a rise in the maximum density of the beam by a factor of 25. At the resulting high current density it would take only 170 ms until a hole is burned through both the liquid metal container inside the target and the lower target enclosure (double-walled safety hull). The liquid metal would spill into the beam line and into the catcher vertically below the SINQ target. Such a failure would result in an extended shut-down period for SINQ.

In order to prevent an insufficiently scattered beam from reaching the SINQ target three independent safety systems have been installed: a dedicated current monitoring system, a beam collimating slit and a novel beam diagnostic device named VIMOS [9]. The latter