Nuclear Instruments and Methods in Physics Research A 625 (2011) 5–10

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

A case for a SINQ-type cannelloni target at the ESS power level

K. Thomsen [a,*], M. Butzek [b], F. Gallmeier [c], J. Wolters [b]

[a] Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
[b] Forschungszentrum Jülich, 52425 Jülich, Germany
[c] Oakridge National Laboratory, Oak Ridge, TN 37831-6466, USA

ARTICLE INFO

Article history:
Received 23 September 2010
Accepted 4 October 2010
Available online 13 October 2010

Keywords:
Solid state
Spallation target
Water cooled
Neutron production
High power

ABSTRACT

In the following short article preliminary results concerning the high-power suitability of a solid-state target cooled by water as in SINQ are reported as available by the summer of 2010. The assessment warrants further and more detailed studies into an approach that appears to combine in an ideal way design maturity, ample positive operational experience, reliability, upgradability and minimum hazards and risks with acceptable neutron production.

1. Background

Since spring 2010 efforts have taken up speed, aimed at selecting the best suitable target concept for the European Spallation Source (ESS). In the light of tight constraints concerning the available time it appears wise to concentrate on well-proven concepts when laying out the world's most powerful neutron source. One such concept is centered on lead-filled zircaloy tubes, "Cannelloni", as employed in the SINQ neutron source at PSI (Fig. 1) [1].

2. Requirements

The following ranking of key requirements applying to any high-power spallation target is adopted for the following as a baseline:

- safety, i.e. during normal operation and in accidental scenarios;
- reliable production of suitable neutrons;
- cost, i.e. during construction, operation and disposal/dismantling and, in addition,
- upgradeability, growth potential.

Whatever be the first choice for a target concept, it certainly is mandatory to have some fall-back solution also in case severe problems surface during the detailed design of the primary choice, or, even worse, problems occur during initial operation. Liquid metal and solid-state targets appear to offer two sufficiently diverse alternatives, but a late switch between concepts would be difficult due to the different requirements of the operating environment. In this paper the focus rests almost exclusively on a water-cooled solid-state target of SINQ type.

Generally, approaches that leave freedom for later variation, improvement and for upgrade are preferable to others, where one is fixed once and forever.

2.1. Safety

There is no doubt that safety and, intimately linked to it, public acceptance of the facility are of utmost importance for any spallation neutron source. In a nutshell as a rather important argument for cannelloni, no useful high-power spallation target can be envisaged, which utilizes less harmful substances as its main constituents compared to pure lead and water. For any given amount of money, environmental impact definitively can be minimized when employing only these comparatively well-behaved and well-understood substances, and accordingly the least problems for licensing are to be expected.

Tritium and beryllium are the only two radioactive isotopes of concern during normal operation. In Switzerland, e.g., it was much easier to license changes in the standard PSI SINQ solid target than the liquid metal Megapie target employing lead bismuth eutectic (LBE).

The direct accessibility of the cooling loop for the safe hands-on maintenance of the circuitry simplifies and eases not only licensing but contributes significantly to high reliability and resulting availability of the facility.

In the most likely accident scenario, i.e. the burning of a hole caused by unintended strong beam focusing, only a small fraction of the total rather limited inventory of lead from a few cannelloni would be released into the cooling water and thus would have still be contained inside the water loop. In contrast to this, burning a hole into the shell of a liquid metal target would potentially release

* Corresponding author. Tel.: +41 56 310 42 10; fax: +41 56 310 31 31.
E-mail address: knud.thomsen@psi.ch (K. Thomsen).

0168-9002/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2010.10.017

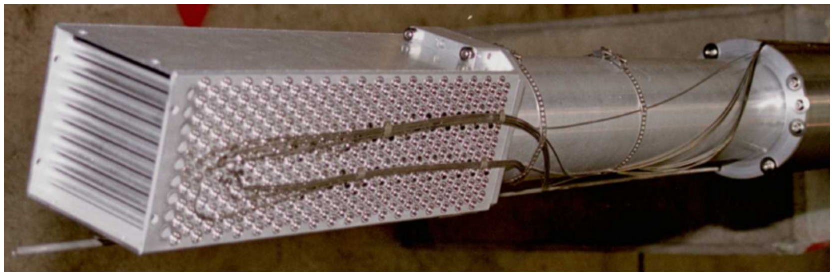

Fig. 1. SINQ target of the basic "Cannelloni" type; tubes filled to about 90% with lead are arranged in a staggered configuration and cooled by water in cross flow. On the side thermocouple connections are visible.

the target inventory towards the surrounding shielding (spill over the moderator and reflector) and thus at least require a long term shutdown of the whole facility for recovery.

In relation to decommissioning and disposal, at least at PSI, there is an established procedure, for which main steps have already been exercised and fully approved by the licensing authorities, for SINQ cannelloni targets.

2.2. Function/neutron production

The primary function of a spallation target is of course to produce neutrons for research with dedicated instruments. This simple statement entails several corollaries and practical consequences.

First, it means that when conceiving the overall system, one has to start with the far end, i.e. representative instruments, which are optimized for the envisaged long-pulse time structure of the neutrons at ESS. Neutron guides, reflectors, moderators, and, in particular, the target itself have to be tuned in a balanced manner to deliver suitable neutron flux to these instruments. It goes without saying that the accelerator in term has to deliver protons fitting in with the demands thus ultimately defined by the science demands.

Concerning the target assembly directly, a long-pulse characteristic grants relaxed constraints with respect to compactness when compared to short-pulse neutron sources, where especially the spallation zone and moderators have to be small to preserve the pulse shape.

As a first approach and basis for further investigation and comparison of different types of targets, the following reference parameters for the proton beam have been assumed:

$$5\,\text{MW},\ 2.5\,\text{GeV},2\,\text{mA (average)},\ \text{sigma}X = 5\,\text{cm},\ \text{sigma}Y = 1.5\,\text{cm},$$

duration of 1 ms, repetition rate of 20 Hz corresponding to a peak current density (time average) in the center of

$$42.44\,\mu A/\text{cm}^2,\ (2000/(2 \times \text{pi} \times \text{sigma}X \times \text{sigma}Y))$$

While issues like waste disposal and the general safety case are well known from operational experience at SINQ, three issues are of immediate concern for a water-cooled cannelloni-type target for the ESS power level and beam conditions:

1. Does it produce usable neutrons?
   a. total flux
   b. time structure
2. Can it be cooled?
3. How long does it survive?

As a very first hint to the ability of cannelloni targets to produce neutrons, and also the inherent growth potential, reference can be made to the experience at PSI with diverse SINQ targets [2]. Only two steps shall be highlighted from the decade-long development, involving a significant increase in neutron production efficiency as a result of replacement of the former standard cannelloni target with the Megapie liquid metal (LM) Lead Bismuth Eutectic (LBE) target in year 2006; see Fig. 2. Inspired by this gain in neutron

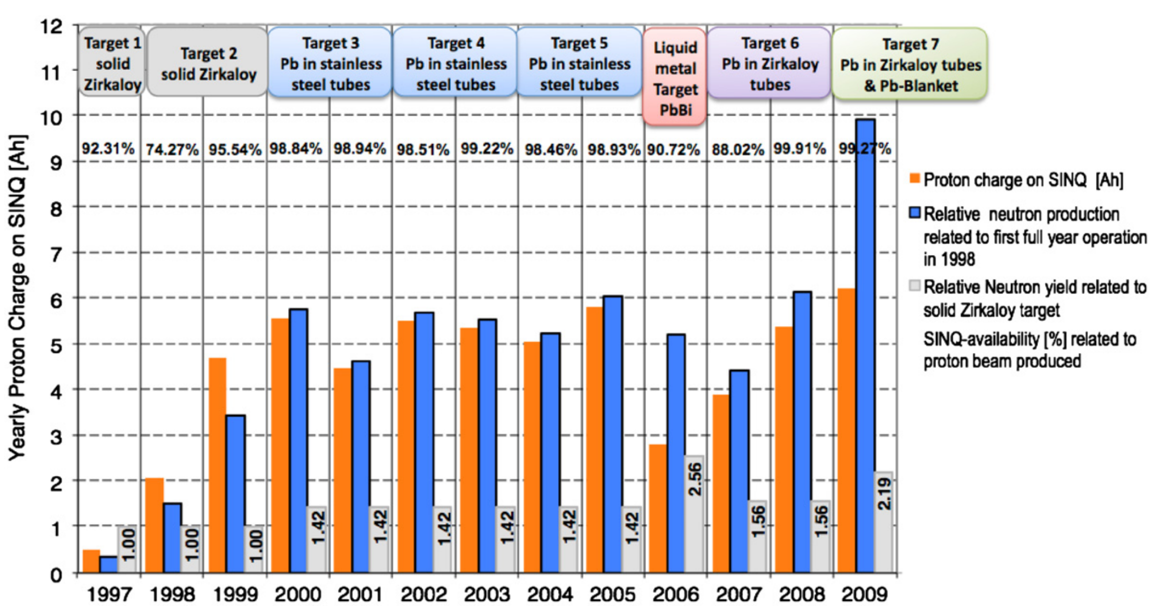

Fig. 2. Overview of SINQ performance; in 2006 with the Megapie LBE target, almost equal neutron fluxes were produced as in 2005, but in about half the time and from half the total proton charge; the enhanced cannelloni target, employed since 2009, reaches 85% of the Megapie efficiency.