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FULFILLMENT OF SELECTION CRETERIA BY CRS4 WINDOWLESS GUN CONCEPT

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1 Scope

A draft list of concepts [5] for the ESS target was established for the 3rd Target Station Concept Selection (TSCS) Working Group meeting held at PSI, Villigen in May 2010.

A comparison of the different target concepts is planned on the basis of an extensive list of (weighted) criteria, the final goal of the TSCS Working Group being the selection of one concept for further study with the whole selection process compiled in a conceptual design report and presented to the ESS Steering Committee in October 2010.

The target station of the ESS Scandinavia Reference Design is essentially the long pulse Hg target station in the ESS Update Design from 2003. For all other concepts, an emphasis is being placed on **engineering feasibility**, i.e. the potential for construction of target systems given **materials**, **heat removal** and **layout** challenges.

On this basis, this document proposes the most relevant criteria that should orient the final choice of the target concept.

This document reports on **target Gun Windowless target**, describing the target concept and systematically **for each "most relevant" criterion**:

- **previous relevant studies** including where possible prototyping and operation under beam conditions in support of quantitative or qualitative estimation of acceptance of criterion.
- **additional studies** required to address specific issues related to a given criterion.
- an **assessment** of how well the criterion is met.

Of course, when information is available for the other criteria (exhaustive list in [5]), or considered to be important by the author for one particular concept, it can be added.

2 References

[1] ESS 2003 Report, Volume III Update Report, Chapter 4, Target systems (EDMS Ref. 1043074 v.1).

[2] The ESS Scandinavia submission to the ESFRI Group on ESS siting – 25th April 2008 (EDMS Ref. 1078809 v.1).

[3] Conclusions Report on ESS-Bilbao initiative Workshop.

[4] Guidelines and tasks description for the Working Group for ESS Target Station Concept Selection: ESS-TSCS (EDMS Ref. 1061104 v.2).

[5] Target Concept Description and Draft Studies List (EDMS Ref. 1073731 v.2).

[6] Target Selection Criteria (EDMS Ref. 1057608 v.2).

[7] Fabich,A.,Benedikt,M.,Lettry,J.,2003.Experimental observation of proton-induced shocks in free surface liquid metal targets. Journal of Nuclear Materials 318, 109–112.

[8] Massidda, L., A CRS4 Spallation Target for ESS Simulations with Armando, CRS4 report 10/66, 2010, http://www.crs4.it/Publications/cgi-bin/tr/repository/crs4_1553.pdf

[9] Maris, H., Balibar, S., Negative Pressures and Cavitation in Liquid Helium, Physics Today, Feb 2000, http://www.aip.org/pt/feb00/maris.htm

[10] Riemer,B., Benchmarking dynamic strain predictions of pulsed mercury spallation target vessels. Journal of Nuclear Materials 343 (1–3), 81–91.

[11] NEA, Handbook on Lead-bismuth Eutectic Alloy and Lead Properties

[12] Moreau, V., A CRS4 Spallation Target for ESS Simulations with Starccm+V5.0, CRS4 report 10/57, 2010, http://www.crs4.it/Publications/cgi-bin/tr/repository/crs4_1536.0.doc

All references and relevant documentation are stored and managed in the ESS Scandinavia EDMS: each participant of the working group has an access to the system (protected by a login and a password) and read/write rights in the dedicated folder.

ESS EDMS address: https://edms.cern.ch/ under "Projects", "External Collaborations", "ESS Scandinavia" (or direct link: https://edms.cern.ch/nav/CERN- 0000077409)

Dedicated folder for TSCS documents: ESS/Project team/Target Station/Pre-Conceptual Phase.

3 *Concept Description*

The concept takes as a basis the reference Hg loop concept of ESS 2003, of which it represents a modification. The concept is only relative to the spallation region of the target loop. It may be in principle applied to any Liquid Metal loop. It is proposed here for the Lead-Bismuth Eutectic (LBE) but is straightforwardly adaptable to a Lead target.

The design is based on a channel of liquid metal with a free surface on the top in contact with near vacuum. There is no structural window between the beam line and the target bulk.

The beam reaches the liquid metal channel from the top free surface, it is oriented with an angle of 45deg with respect to the vertical. See Figure 1

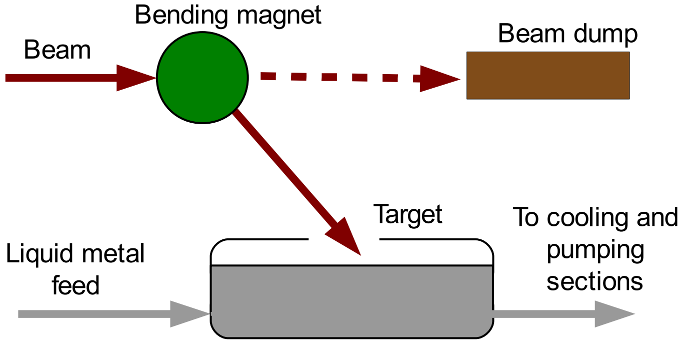

Figure 1: sketch of the target concept

The design of the beam line has to be modified with respect to the ESS 2003 because the beam entrance is no longer horizontal.

The target geometry section is shown in Figure 2. The width and height of the channel are related to the beam size. For a sigma of the beam of 1.5cm and 5 cm the channel width is 8 cm and the height is taken equal to 60 cm.

These parameters may be adjusted to fit the energy beam power deposition.

The concept presented here is based on the PDS-XADS FP5 project, a windowless channel like target that has already been dimensioned and simulated for a relatively similar proton beam: 2.6

MWth, 6mA and 600 Mev. In the framework of this project, the spallation target was conceived by Ansaldo and developed mainly by CRS4 and ENEA.

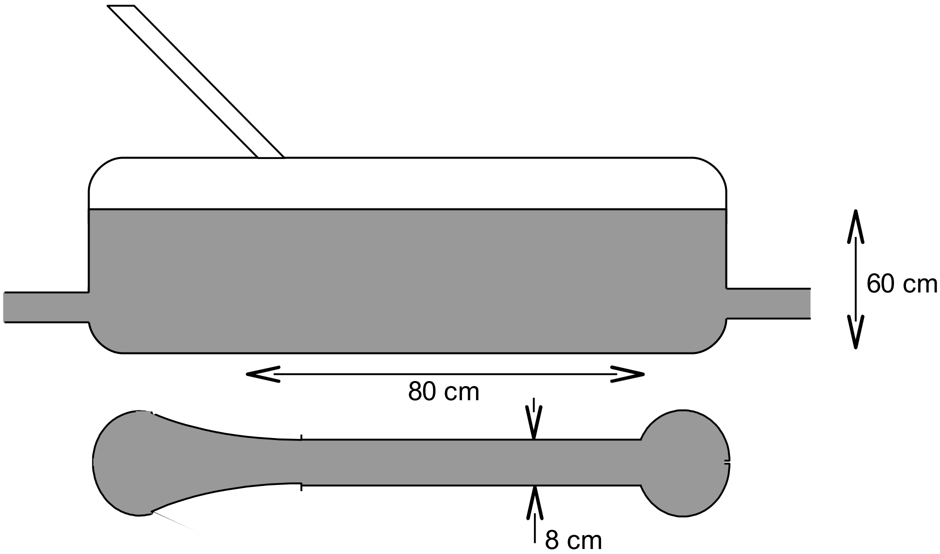

Figure 2: target geometry

3.1 Window or Windowless

In the ESS 2003 report, it is specified that the main reason why a windowless concept has not been considered is related to the splashing phenomena that can take place at the free surface of the target and that are estimated to reach up to 10m/s velocity.

This speed would cause LM droplets to reach up to 5m height, and potentially accumulate on distant parts of the system, causing deposits, stresses and other effects.

The estimation of the 10m/s is based on previous experiences with similar targets and on experimental tests operated with Mercury. The experiments show that the splashing velocity is directly proportional to the beam intensity and is inversely proportional to the square root of the beam size. This suggests a direct relation between splashing velocity and the deposited energy density. [7]

The relation between the splashing velocity and the time structure of the beam power deposition law is more complicated and less understood. It has only been tested for sequences of short pulses. The results show that if the time gap between two pulses is large enough there is no longer a superposition effect of the pulses. [7]

The dynamic effects must be related to the pulse duration and the splashing velocity is expected to be much less than 10m/s in the long pulse conditions.

This idea is confirmed by a numerical analysis [8] but would be also better confirmed by some experimental activity. In the transient simulations the maximum splashing velocity recorded is lower than 1 m/s resulting in an height lower than 5 cm. This is a conservative estimation due to the difference of purity between the Mercury in the experiments and the foreseen LBE purity.

In the windowless design proposed here, the LBE should be free of almost all the dissolved gaseous impurities which are continuously removed by degassing at the free-surface [9]. Solid impurities, which could be the seed for cavitation should be actively filtered out. The LBE is expected to have almost no seed for cavitation and thus behave as a solid with regard to a short time traction.

The simulation performed with the Armando code is giving the correct velocity of splashing for a "dirty" Mercury cup. This velocity is manly controlled by the value given to break the bond between the simulation particles, 150 kPa. This value is completely empirical [10] and is reasonably expected to be higher for purified LBE. However, still keeping this value, the simulation with the Armando code gives a maximum splashing velocity below 1 m/s for LBE in the configuration of the CFD simulation [8].

3.2 Which Liquid Metal?

The choice of the LM for the circuit of ESS 2003 and for the proposed concept is based on the same considerations, for material compatibility, radioactivity issues, simplicity of the circuit. Here, there is anyway also the need to have a low vapor pressure at the operating temperature. This essentially precludes the use of Mercury and puts a neat preference on LBE, or Lead as a second choice. The LBE vapor pressure is lower than 0.01 Pa in the supposed operating conditions and can be made much lower. Direct extrapolation for pure Lead, needing an higher minimum temperature is compatible with the same 0.01Pa constraint. The vacuum pump of the target serves only to remove the gaseous impurities of the material, mainly the spallation products. The vacuum is high enough to be compatible with the terminal part of the beam line.

The advantage of LBE over Lead is its lower melting (125 C vs 323 C) point and therefore its greater versatility for the operating conditions. Above 323 C, both liquids share almost the same vapor pressure-temperature curve.

The drawback of LBE is the large quantity of Polonium produced by spallation. However, the Polonium issue should be solved in the framework of the CDT EU project aimed at building a fast neutron facility using an inventory of about 4,000 Tons of LBE that will also highly be contaminated with Polonium.

3.3 Selection of structural materials

The stress levels in the target are expected to be much less with respect to the 2003 concept. The target is not closed and therefore the mechanical load due to internal pressure is not an issue.

The material has to be chosen on the only basis of material compatibility at the operating conditions with very limited requirements on mechanical strength and radiation damage.

Moreover there is no longer a window that itself requires a particular care for material selection and structural requirements. The LBE handbook allows the choice of the possible compatible structural materials [10].

3.4 Pulsing effect in the liquid

The liquid is not closed and under positive pressure, therefore the concerns for cavitation damage and pressure waves on the structure may be relaxed. The addition of small bubbles to increase the compressibility of the liquid shall not be adopted to avoid helium leak in the beam line. Moreover, the liquid close to the free-surface is at low pressure, and the presence of bubbles in the flow would promote splashing under the thermal pressure wave effect.

3.5 The liquid metal loop

The design of the liquid metal loop shown in the figure below is simplified with respect to the 2003 concept. Two auxiliary circuit have been removed: (i)There is no more the auxiliary circuit for Helium, for the bubbles to be introduced in the liquid, (ii) there is no more the auxiliary circuit for the cooling of the window.

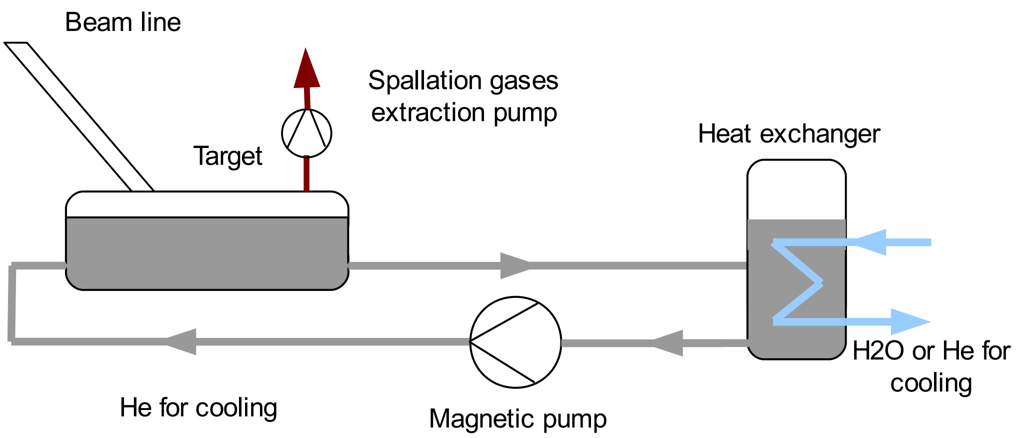

Figure 3: liquid metal loop

Such a loop has been simulated with a good approximation of the real beam power deposition. The inlet temperature of of the LBE is 300 C (573 K), the average beam power deposited is 2.3MW, with a flow rate of 28.2l/s the maximum temperature in the bulk is 510 C, the maximum vapor pressure is quite below 0.01 Pa. The free surface appears almost stationary and very stable in the simulation [11].

3.6 Beam line modifications

As mentioned this windowless concept requires to beam to be vertical or at least inclined but not horizontal. A different configuration of the beam line has therefore to be considered with respect to the ESS 2003 design, the number and position of bending magnets and associated beam dumps may change. It can be one more if the beam travels horizontally in depth, or one less if the beam is brought closer to the ground surface before traveling horizontally.

4 Criteria evaluation

This paragraph 4 contains the list of sub-paragraphs that should address the “most relevant” criteria among the exhaustive validated in [5].

Proposal:

The § 4.4 “The need for R&D” should be the most important selection criteria and should treated in priority.

4.1 Criteria associated with cost

This section describes criteria associated with costs:

Cost of construction/commissioning

In confront with any other LBE or Lead window spallation target loop, one saves the money for the auxiliary systems no more needed for bubble injection and the external cooling of the target window.

Cost of decommissioning/disposal

Same as before. Only one fluid (LBE) would have to be disposed.

4.2 Criteria associated with Performance during operation

This section describes criteria associated with performance during operation:

Neutron performance - Time Integrated flux instruments (SANS)

Essentially independent of the presence of a window.

Number of possible beam lines

Idem.

4.3 Criteria associated with Safety

This section describes criteria associated with performance during operation:

Ease of containment implementation

Containment of volatile products of spallation is automatically performed by operating under near vacuum. Loss of integrity of the containment system would result in air ingress, very easy to detect because of a pressure increase, and not in external release of contaminated volatile products.

Environmental impact beyond design basis accidents

LBE naturally freezes under ambient condition.

Ease of licensing approval

The CDT directory board is confident with licensing a fast neutron spectrum facility requiring the disposal of about 4,000 Tons of LBE highly contaminated with Polonium.

4.4 Criteria based on Associated Risks

The need for R&D

The R&D in this concept is primarily related to the possibility to conduct an experimental campaign on the splashing effect and free surface stability of liquid metal bath under long pulse conditions similar to the real operating conditions, in order to properly validate the simulation results. Special care should be taken to operate under near vacuum condition and to evaluate the impact of the degree of purity of the spallation material.

Moreover it is necessary a mechanical design of the target vessel, this shouldn't be challenging due to the low intensity of mechanical loads.

4.5 Criteria based on Availability

Lifetime of TMR

This evaluation should take into account irradiation damage sensitivity and liquid metal environment sensitivity.

Evaluation...

4.6 Criteria based on Maintainability

Time required to perform maintenance/service

Almost no maintenance should be necessary in the spallation zone.

Ease of TMR exchange

Evaluation…

4.7 Criteria based on Upgradability

Possibility to increase performance of existing system

The design proposed appears far from any structural or fluid-dynamic limit and has big margin of improvement in terms of power to be deposited.

5 Summary

This summary could present a short and summarize “pros and cons” list.…

Pros:

- extremely simple and versatile design
- large margin for optimization and upgrading
- intrinsic safety due to the below atmospheric pressure operation.
- Only one fluid in the spallation region (only one fluid irradiated)
- No electrical system close to the beam line (no need for electromagnetic shielding)
- No mechanical part in movement (no solicitation on junctions) close to the spallation region.
- Easy capture of volatile spallation products
- Easy visual inspection of the spallation region integrity
- Possibility to control the flow quality by direct visual monitoring
- almost no maintenance foreseen in the spallation region
- May require one bending magnet less.

Cons:

- may require a continuous purification from solid impurities
- far too simple
- the “splashing” issue must be settled (is there any, and in case, how much and under what

condition)

- may require one bending magnet more.