n_TOF Target #3
Production Readiness Review

29 May 2019
Thanks

Many thanks to Marco for the perfect organization of the review and for his traditionally excellent hospitality, and to all the speakers for the time and care in preparing and delivering the presentations.

The Target#3 team is made of young and motivated experts covering different disciplines and with an excellent internal communication. This is by itself a guarantee of success!
Key messages

• We have been impressed by the systematic and methodological approach followed by the project, starting from the original Solution 1 and going through 3 other versions before arriving at the present Solution 5.

• Solution 5 appears as a very good design that combines simplicity with sound technical choices and fulfills at the same time performance and safety requirements. It has now reached the maturity required to go into production. We presently do not see any evident showstopper or missing aspect that might hinder the successful operation of the spallation target starting from 2021.

• In particular, the simplification with Solution 5 seems to have covered many of the concerns raised for solution 4 and all points raised at the last review were covered – with the exception of the N2 risks where there is no previous experience.

• Go ahead and start production! (to be ready in time for installation...)
However...

• This design presents some new aspects, in particular related to the use of Nitrogen, for which we cannot rely on existing experience from other laboratories.

• On top of that, the design has been so far concentrated on satisfying the required nominal operating conditions but has not analyzed all possible accidental scenarios and potential risks.

• We believe that at the present stage of the project our main contribution should consist in a “risk analysis”, enumerating the main risks (and possible mitigations) as observed from our side.

• This risk exercise does not replace an internal risk analysis that should take place soon within the team, to identify other potential risks and possibly introduce in the design some mitigations for accidental conditions before the production is too advanced.
Risks

- Outgassing and/or erosion from lead into nitrogen circuit.
- Degrading filter efficiency
- Insufficient filter efficiency for certain nuclides (e.g., halogen/Xe nuclides)
- Degrading leak rate of nitrogen at blower
- Access close to target vessel for work/repair etc. of installations by nToF or other groups (e.g. upstream beamline instrumentation, mobile shielding, irradiation station etc.)

Mitigation
Continuous monitoring of relevant quantities:
- activities in the cooling circuit
- activities in ambient air of areas accessible during operation
- nitrogen leak rate
Plan for regular testing of filter efficiency
Systematic failure risk analysis of any component installed in vicinity of target, robust design, remote inspection and handling

Recommendations
- Permanent installation of activity monitoring on nitrogen cooling circuit and of air in accessible areas.
- Implementation of continuous monitoring of nitrogen refill/loss
- Consider implementation of interlocks in case of sudden significant degradation of performance of cooling circuit
- Consistent use of steel with low content of cobalt (at maximum 0.1% in weight) for all steel components (vessel, frame structure above vessel etc)
- Plan and document dismantling procedure in LS4 (work-steps, methods, shielding, dose planning)
- Foresee sufficient resources and time for commissioning.
Risks 2

How can we detect an unexpected increase of the temperature inside the target if the thermocouples failed? Would it be possible to measure the nitrogen temperature at the outlet of the target or a pressure-drop?

In case of nitrogen cooling shut down, is the beam stopped automatically?

Welding/brazing: for all critical configurations (in particular when non destructive examination are not possible) welding/brazing qualification shall be carried out on representative samples.

Consider that the brazing junction used for the thermocouples is a weak point.

Open point: the lead assembly with the anticreep plates will probably be a complex task to avoid damaging of the lead blocks (deformation). The installation of the thermocouples will also be sensitive. The assembly procedure shall be studied in detail because of limited clearance and tight tolerances.

No information was given concerning the fabrication strategy. A spare part strategy shall be defined (complete or partially fabricated) in order to minimise the risk.

Schedule: to be able to respect the delivery date (mid 2020, one year from now), the fabrication shall start in the coming weeks (design to be frozen soon).
Recommendations related to the beam parameters:

- Evaluate the risk related to the removal of the final quadrupoles in the FTN transfer line.
- Evaluate the risk of a failure of the SEM grid installed upstream the target (broken wires, electronics,...) and assess repair/exchange possibilities.
- Assess potential accidental failure scenarios that could reduce the beam size such as:
  - malfunctioning of the PS RF cavities responsible for the bunch rotation (reducing the momentum spread of the beam).
  - malfunctioning of quadrupoles in TT2/FTN.
- Ensure that the new SEM grid is compatible with the current operational beam size and also the request for larger beam size on the target (frame dimensions, wire spacing,...) to avoid additional beam loss.
Risks 4

- Weld inspectability and control of penetration. Several welds are volumetrically not inspectable by NDE techniques. Specially for the one that are performed manually by TIG welding the weld preparation should guarantee a minimum weld penetration on which in turn the calculations rely. For these cases it is strongly suggested to consider a weld preparation including a chamfer and a filler material in order to mitigate the risk of uncontrolled/incomplete penetration.

- Material for the moderator windows. In the past target, 3D-forged material was selected for the windows, produced within a well-controlled thermomechanical route in order to minimize corrosion risks. For reasons of costs and schedule, for the prototype (and eventually production parts) rolled plates are now considered in place. In parallel to the actions carried out to qualify rolled material that we fully endorse and acknowledge, it should be checked whether on a schedule and budget basis forged material could still be envisaged in order to limit the risk induced by the use of less controlled products such as plates out of the shelf.

- Possible outgassing from the lead is considered by RP as a potential issue. This risk might be addressed by simulations complemented by outgassing tests in order to identify a worst case scenario in case of a substantial gas extraction occurring in operation.

- Post Irradiation Examinations (PIE) of components of the previous targets are not formally included in a testing programme following the dismantling of the target. Such tests could be extremely useful (namely the effect of the long exposure to borated water of the moderator windows) in order to confirm technical solutions envisaged for the present target. It is strongly suggested to define a minimum PIE test program compatible with the project schedule that could run in parallel with the construction of the new target to at least document the expected behavior of the materials based on previous experience.
Risks 5

• Although there were initial concerns with welding the bi-metallic component the prototyping looks to have found a solution by increasing the thickness. There is still risk with this, so care must be taken with examination and testing after welding.

• The same is said for the EB and TIG welds in general. CERN have much experience with EB welding and TIG, but care should be taken with the validity of the qualifying welds and post weld examination.

There doesn’t seem to be a great deal of instrumentation in place to monitor target operation beyond the thermocouples and SEM screen.

• What is there in place to monitor water leaks from the moderators? Would a humidity sensor in the target area be helpful?
• Is the moisture content of the N2 gas known and monitored? – so as to prevent lead corrosion. (Is there a dryer in the system, and is one needed?)
• What is there in place to monitor N2 leaks in operation?
• The CFD analysis of the moderators showed no stagnant areas, but the flow was not very evenly distributed. Is this a concern?
• Is it likely to cause H2 bubbles to form in the slow moving areas? If they do form is the flow sufficient to extract them from the moderators, particularly the EAR2 moderator?
Risks 6

1. Beam size significantly smaller than predicted leading to much higher peak temperatures
2. Loss of temperature sensors in the core (loss/insufficient contact of thermocouples with Pb or feedthrough failure)
3. Lower than nominal weld throats, particularly of partial penetration joints
4. Incomplete/inaccurate material models for Pb affecting simulation reliability

Mitigations

• Risk 1. Perform a risk assessment to ascertain whether this is a possible event. Weigh likelihood against severity and, if justified, propose corrective measures

• Risk 2.
  a. Consider modifying the design of the thermocouple fixation to ensure Pb temperature is measured and not stainless steel clip
  b. Assess risk of failure of feedthroughs. Consider redundancy or improvement of feedthrough design
  c. Consider whether (excessive) temperature can be inferred from other indirect measurements (external thermometers, increase in pressure losses related to clogging ...)

  a. Risk 3
    a. Determine minimum guaranteed weld throat and reperform simulations with that value (if lower than considered).
    b. Make sure safety coefficients in weld assessment take into account (lack of) inspectability
    c. Perform a convergence study to assess effects of FEM element size for welds

  b. Risk 4
    a. Take into account effect of grain size in Pb creep and fatigue behavior. If literature data are unavailable, compensate with adequate safety margin
    b. Complete Pb material models with characterization at high strain rate, high temperature dynamic tests (Split Hopkinson Bar tests)
General Recommendations

• The project team has come up with a sound and elegant design that responds to the physical and mechanical requirements (nominal working conditions). However, it is recommended to complete the study by identifying and assessing the design against accidental scenarios.
Risks 7

- Risks:
  - Nitrogen chemistry knowledge poorly developed. Consequences are unknown: By-products\reactivity\erosion enhancement;

- Mitigation:
  - Continuous monitoring of the gas phase composition before and after filters;

- Recommendation:
  - Install gas analyser as from t0;
  - Keep looking for literature and or experience data on nitrogen related chemistry;
  - Post mortem analysis of target #2 ASAP in order to assess common components\structures or assembling procedures
Risks 8

There is a potential worsening of the resolution function at EAR1 and EAR2 introduced by the moderators spacers. Suggestion is to estimate the degradation of the resolution function with the present design of the spacers, and if needed to revise the spacers optimization considering resolution function as important as the level of epithermal neutron flux intensity.

How to early detect malfunctions in the target:
- insufficient cooling at hot positions;
- deformations of the lead or other materials;
- chemical degradation of the materials (Pb, Al, SS) in the target;
- accumulation of particles or materials in any point of the circuit;
- accumulation of radioactive isotopes any where in the circuit;
...

Are there already sufficient instrumentation in the target or in the circuit? Do you have reference values best estimate for the measured parameters during operation? Could use of additional instrumentation at least during the first months of operation to help early diagnostic.