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CAST ^{3}He TDR, Review Committee's Report

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The committee thanks the CAST team for their documentation and clear presentations. The Review committee did not find any significant problems in the technical aspects of the system as far as routine operation was concerned, finding that the 'Requirements and Functionalities' of the ^{3}He system were largely satisfied.

There were nevertheless some points to be addressed concerning single and multiple point failures of components which could lead to loss of ^{3}He. These points are contained in Section I below together with a list of mandatory items, strong recommendations and suggestions for consideration by CAST. Section II contains mandatory items and strong recommendations on general mechanical and cryogenic safety considerations which were not fully addressed in the TDR. Section III contains the summary and conclusions.

I. ^{3}He Operational, cost and design items

1. Vacuum systems and detectors which can be linked to the vacuum side of the cold X-ray windows. MANDATORY

Provide a diagram all the systems (vacuum systems and detector) attached to the vacuum side of the cold X-ray windows and identify all possible leakage paths of ^{3}He from system in the event of a rupture of a window.

Quantify the maximum loss of ^{3}He in the case of a quench with 120 mbar ^{3}He, which remains contained in the cold bore by a valve failure which results in a rupture of a window.

- *VT1->4 gate valves close after 1-2 secs (normal)*
- *One or more VT valves fail to close*

Add additional interlocks on external vacuum systems to prevent losses of ^{3}He. Evaluate the pressure limits of the detectors and strengthen or protect them from over-pressurisation so as to contain the ^{3}He within the system.

2. Cryo-valves MANDATORY

Eliminate any possibility of trapped volumes containing cold cryogenics fluid which could ultimately pressurize when warmed up. The cryogenic valves shall conform with European Standard EN1626.

3. Manual valves which must be left open to ensure safety MANDATORY

For example Vs1, Vs2, V003 Vgate_R, V gate_F

Mechanical locking system to prevent the closing of a valve required to avoid against human error

4. What if quench trigger fails to reach the ^{3}He system interlocks but still protects the magnet? STRONGLY RECOMMENDED

Add a second – slower quench signal derived from pressure rise in cold bore or a temperature rise.

5. Cold X-ray windows STRONGLY RECOMMENDED

If all safety systems fail, the windows can be pressurized to ~ 2.7 bar during a quench with the full charge of ^{3}He in the cold bore. It is understood that tests are planned to measure the mechanical characteristics of the existing windows which are expected to hold at least 2.7 bar.

2. *Include in the Cryolab tests, a test of fatigue due to TAO's (see point 5)*
3. *Make at least 4 spare windows in case of breakage during installation or operation.*

4. *Test the window to 1.5 times the design pressure and check for plastic deformation of the strong-back.*
5. *Make a break test to establish a global safety factor.*

6. Allowable loss of ^{3}He

Estimate the annual operational losses of ^{3}He in normal running.
Has LLNL specified any limit to losses? Is CAST expected to pay for the losses?
What is strategy if a large quantity of gas lost? Ask LLNL whether they will replace the gas in this event?
Protect all flexible pipes linking magnet and off-magnet gas system. Use specially protected multi- walled flexible pipes.

7. Thermo-Acoustic Oscillations (TAO)

Whenever V cryo_R is opened there may be large amplitude TAO's. Could this produce wear or fatigue on the X-ray cold windows?
Use the present TAO simulation program to identify the range of pressures where this may occur.

8. Errors in filling of cold bore due to human errors

A human error could introduce the full charge of helium into the cold bore which could in case of a quench produce a pressure in excess of the pressure limit for those windows presently-installed.
In the initial running periods, consider filling the storage vessel with only part of the 1m^3 ^{3}He so as to limit the maximum pressure attainable when filling the cold bore

9. Manipulations of valves on gas system

In view of the potential for human error, how will the valves and pumps be manipulated?
Will all the valves be manipulated in situ or will they be controlled from a central panel. Will there be an interlock system (hardwired or computer) behind the controls to prevent erroneous sequences of manipulations?
Aim to eliminate to a maximum the possibility for human error in manipulation of the system.
Define clearly the procedures, train the personnel and restrict access to the system to personnel on a pre-defined list. Since the system will be used by a number of people, consider adding a PLC, or similar, to supervise and interlock the modes of operation of the system.

10. P $_{3He}$ pump breakdown

What is the strategy if the pump breaks down?
Can the gas in the cold bore be removed?

11. Manual cryo needle valves

What if the spindle of the needle valves becomes stuck? (Open or closed)
Study the consequences and actions if this does arise

12. Table of valve failsafe status (6.6)

Specify the status when compressed air pressure failure.

13. Effect of impurities or small circuit leaks in ^{3}He system

If they accumulate over a year of operation – could they block the filters or other circuit elements?
T Niinikoski believes they cannot.
In the first year of operation, make more frequent checks on the filters to make sure no significant accumulation.

14. Test all valves (EP and Cryo-valves) before installation

Test cryo-valves at operating temperature in the Cryolab.

15. Retro-diffusion of oil vapour to the cold bore (and onto windows)

When evacuating cold bore at T~ 70K with P $_{3He}$ pump, retro-diffusion could occur.
Evaluate the possibility, consequences and preventive measures against hydrocarbon contamination in cold bore and on cold x-ray windows.

16. Storage vessel for ^{3}He
If it might eventually be used to transport ^{3}He back to LLNL, ensure design satisfies transport regulations.

17. Rupture discs
Avoid using rupture discs made from graphite.

18. Project cost estimates
Do they include manpower and design?

II. <u>Safety issues</u>

1. Safety Rules and regulations MANDATORY
Safety rules and regulations shall be applied (CERN rules: D2, IS47…, European Directives etc). MANDATORY. Contact SC-GS (G. Lindell) in the event of questions.

2. Definition of pressure references for all volumes / components MANDATORY
Produce a table containing as items the various equipment and volumes in the gas system (inside and outside the cryostat) together with the following specifications:

Design pressure
Maximum allowed pressure
Component that protects at the maximum pressure

These parameters are in any case essential for the construction of all new vessels to be used in the system.

Maximum pressure in cold bore – systems to limit pressure build up.
The design should steer the narrow path between eliminating to the maximum the potential sources of loss of gas or leaks and the need to ensure the protection of all volumes to their maximum allowed pressure. There was a discussion on whether a standard electro-pneumatic valve or a cryo-valve can be used also as a check valve by exploiting the fact that these valves will be forced open when the pressure difference across the valve exceeds a limit. The Security Commission's view is that the check valve function is not an integral part of the functions of the valve and it is not certified as a safety valve and is not able to be routinely checked.

With this optic, the ability to protect against an over-pressurisation of the ^{3}He gas pipe-work was scrutinized for three cases below:

2.1 Normal magnet quench
At present, the maximum pressure in the cold bore is stated at 1.2 bar (i.e. 'rounding up' 0.94 bar x 1.2 SF) considering a quench at 130 mbar (@1.8K). This will be the result when the safety elements and the quench trigger work as planned.

2.2 Normal magnet quench with component failure
The maximum pressure value rises to ~ 2. 7 bar if the safety elements in the system do not connect the cold bore to the expansion vessel for any reason.
The check valve Vcheck_F should open with a pressure difference of only 30 mbar. Normally the two manual bypass valves (V cryo_F1 and V cryo_R1) are open and allow a small gas flow around the check valve and the cryo-valve in any case. The cryo-valve (Vcryo_R) should be forced open at ~ 2bar (not guaranteed). At ~ 1.5 bar pressure difference, the warm EP valves are expected to be forced open due to their manner of construction (they even may start to open at >1.1bar). If 1.5 bar pressure difference is needed to keep open the EP valves, then after a quench there will be 1.9 bar in the cold bore and 0.4 bar in the expansion volume.

MANDATORY
Make a risk analysis
Consider the influence of the bypass valves V cryo_F1 and V cryo_R1 on the functioning of the check valve Vcheck_F.

STRONGLY RECOMMENDED
Consider adding additional security elements in order to assure that the any pressure above 1.2 bar can be vented from the cold bore. For example, consider replacing V cryo_R with a cryo-valve combined with a relief valve function as in the LHC quench valves (set at 1.0 bar)- ask A Perin AT-ACR.
As an alternative, consider a rupture disc linking the cold bore to the expansion volume?
Check whether the forced-opening pressure threshold of the EP and cryo-valves is dependent on the compressed air pressure.

2.3 Exceptional pressurization due to large quantities of undetected cryo-pumped air

In this case, a quench will not raise temperatures so high as to produce a rapid pressurization from the layers of solid air, but a sustained rise in temperature of the whole magnet (e.g. in the event of a break in the cryostat isolation vacuum) would slowly increase the pressure. The committee was concerned that there was no sure way to protect the magnet from a dangerous pressurization in this extreme case. (Note that if the 30 litre cold bore was filled with cryo-pumped air and then heated, a maximum pressure of ~ 20 bar could result).

MANDATORY
Make a risk analysis
Any scheduled warm-up of the magnet must be carefully supervised and all volumes pumped continuously.

STRONGLY RECOMMENDED
Consider adding extra securities to the system, for example:

- *A recognized security relief valve in parallel with V cryo_R* <u>*or*</u> *a cryo-valve combined with a relief valve function as in the LHC quench valves (set at 1.0 bar)- ask A Perin AT-ACR*
- *Investigate if a cryogenic 'diverseur' exists which can limit the pressure in cold bore to below 1bar?*
- *A rupture disc linking the cold bore to the isolation vacuum or preferably, a double rupture disc linking the cold bore to the outside of the cryostat(and a helium containment balloon?) Note that this is the only security which would work in the event of all safety valves being stuck closed due to cryo-pumped deposit. The pressure limit for the rupture disc should protect the pressure limit of the ^{3}He pipe-work inside of the cryostat (believed to be 3bar – M Genet TS-MME)*
- *Investigate how to identify or minimize air-leaks into the cold bore region (cold traps at entrance to cryostat? Routine checks in vacuum with residual gas analysers?*
- *Contact Serge Claudet AT-ACR for an exchange of experience re: protection from and detection of leaks in installations connected to 1.8K cryogenics systems.*

3. Sizing of safety devices MANDATORY

Sizing of all safety devices (rupture discs/safety valves): calculations shall be done to make sure that the sizing is done according to the worst case scenario (quench, rapid vacuum loss, evaporation of trapped air etc.).

III. <u>Summary and Conclusions</u>

In order to clear the way for the final design and ordering of components, CAST is requested to send rapid feedback to the Review Committee on the points raised above. At this point a follow-up meeting or video/audio conference could be arranged if required.