VLHC Accelerator Technologies Workshop, Jefferson Lab, February 8-11, 1999
Cryogenics and Beam Screens Working Group

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CHARGE

- Cryogenic parameters and issues for various choices of magnet technology
- Beam screen design requirements
- Reliability and maintenance
- Possibilities for new technologies and the need for R&D

OVERVIEW

The session started with four overview talks to update the group since most of the members had not been involved with VLHC since the FY94 Working Group at Ind. U.

Rode	Charge, Previous Working Group Results and General Cryogenic Issues[1]
McAshan	Low Field Cryogenic Design[2,3]
Peterson	High Field Cryogenic Design[4]
Grobner	High Field Beam Screen: LHC Design and VLHC Issues

BEAM SCREEN

The discussion started with the LHC beam screen system. At 1.9 K one has excellent adsorption but even if one neglects the cryogenic impacts one requires a shield to prevent adsorbed molecules from being continuously recycled by scattered photons and by photoelectrons. The regeneration interval required is much longer than a year.

The LHC primary cryogenic screen loads are Synchrotron radiation and photoelectrons, but resistive losses and nuclear scattering are not negligible.

Both 4.5 and 20 K high field magnets will require a beam screen due to beam lifetimes; without out it CERN data implies warm-ups every 50 hrs. LHC requires solutions for both their 4.5 & 300 K magnets and has a major R&D effort in progress. Additional R&D will be required for VLHC, two options exist, fig 1:

1. Physical absorption: a) shield is required
   b) absorber (e.g. metal sponge) is required
   c) regeneration 20 K, tri-monthly

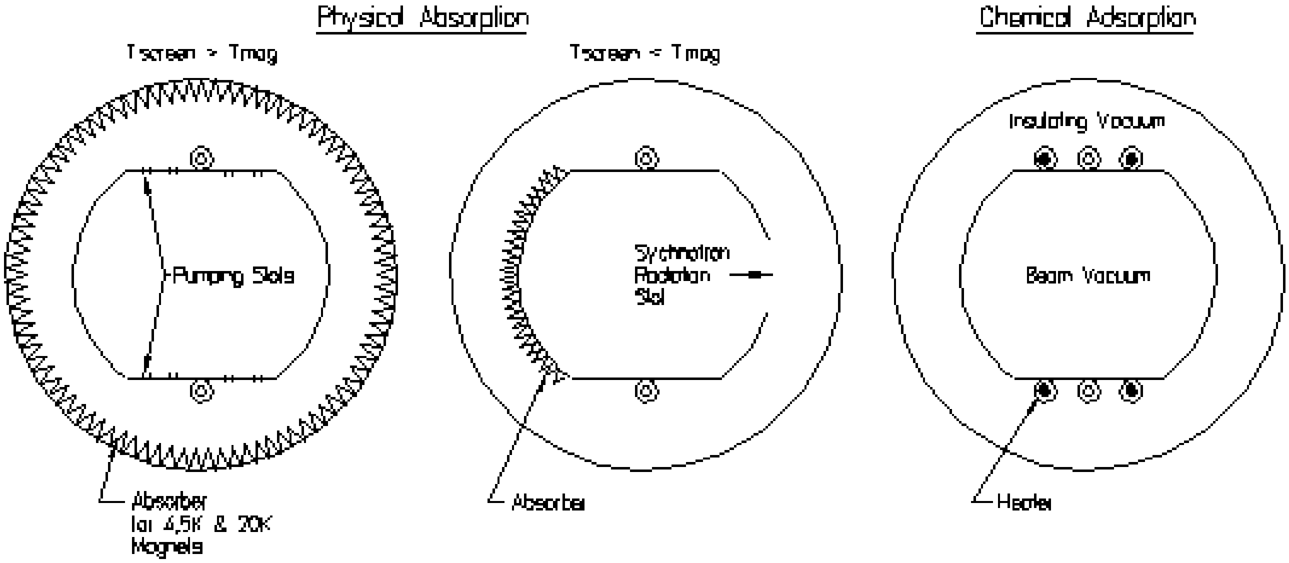
2. Chemical adsorption: a) independent bore tube is required
   b) regeneration 600 K, annual
   c) magnets are kept at their operating temperature
   d) finite life

CRYOGENIC PARAMETERS & ISSUES

The cryogenic issues for every accelerator have always been and will continue to be:

- operating temperature,
- temperature gradients,
- temperature stability.

Figure 1 – VLHC Beam Tube Options



From both a capital and operating cost stand point (of the magnet and cryogenic joint system), as well as availability, it is desirable to switch to sensible heat from latent heat systems; e.g. Nb_3Sn magnet operating between 4.5 & 5.5 K vs. 4.5 & 5.0 K

For NbTi magnets the short sample curves are such a strong function of temperature that elevated temperatures are not an option in fact lower temperatures are often used. For Nb_3Sn with its much higher critical temperature the integrated design optimization may be very different; also there may be major differences between the high and low field optimizations. These optimizations are trade off between:

Magnet short sample,
Cryogenic complexity and availability,
Cooling passages and cryostat sizes.

One of the most important parameters that drives both the cost and availability is string length and / or recooler spacing. This often is driven by temperature requirements (actual and history) for beam injection which can easily add 10% to the cost. It must also be noted that the costs of the HERA and LHC distribution systems are very similar to the total refrigerator cost.

RELIABILITY AND MAINTENANCE

There is little that one can say about this for cryogenic systems but that it is just good engineering practice. For example, in the SSC, there were not redundant turbines, but the cold box was designed such that if one turbine failed the system could run at reduced capacity without it. There were however, some redundant warm compressors. Load sharing for having a plant down or part of a plant down was planned and such issues can greatly extend the required operational envelope.

The VLHC requires an integrated design; single system optimizations will lead to very poor project designs. In addition cryogenic system innovations for VLHC will not come independent of magnet innovations. Unlike, for example, RF or instrumentation and controls, the cryogenic system technology is not separate from the magnet technology. The magnet design and cryogenic system design should be designed as one thermal system. The concepts for the low field "pipetron" illustrate this co-evolution of designs for a magnet and cryogenic system perfectly. **Therefore, we suggest that rather than having a separate cryogenics working group at an accelerator technology workshop, magnet working groups at the magnet workshops should include a few cryogenics people.**

System optimizations require trade-off's between efficiency and availability; the most efficient systems usually do not provide adequate availability. One also requires up front itemization of all off design modes; the configuration is often not controlled the primary mode but by one of the off design modes. The SSC cryogenic system had 22 operating mode; one of which was bore tube regeneration.

Scaling LHC is not an option; a simple magnet cryogenic system is required for VLHC. The Snowmass 138 km LHC scale up would have had 8000 tunnel cryogenics valves (1 valve per dipole average). These valves would more than eat up the entire cryogenic un-availability budget.

One of the continuing issues is having qualified vendors; will there be any cryo system vendors in 15 years? In this country we have seen the industrial cryogenic expertise decay over the past 20 years, due to retirements and corporate decisions that large refrigeration systems are unprofitable. We have cryogenic valve manufactures that do not have the expertise to build a non-standard product valve. There are no large He coldbox manufactures remaining in the US and only three in the world (2 in Europe & 1 in Japan). VLHC may have to restart the large helium cryogenics business.

- We must maintain core competency within the government lab community
- We require smart procurements / full time resident inspectors

- We must be prepared to deal with costs and time required for vendor development

There will be significant vendor development required for procurement of a VLHC system; one must expect that it will cost more than our scale-up of present systems predicts.

While optimizing life cycle costs (5, 10, or 20 yr.) vs. capital costs is motherhood, it must be stated. While DOE guidance may say 20 yr., in the past when budget cutting to reduce capital costs starts (TEC), one does good to maintain 5 yrs.

REQUIRED R&D; PRIORITIZED

The Working Group identified seven areas of required R&D and then attempted to prioritize them. After a lengthy discussion, we broke them in to three groups and then prioritized them.

NON VLHC FUNDED R&D

1. Screw compressor efficiency (FY94 recommendation)

This one component accounts for more than half of total inefficiency of a refrigeration system. We use screw compressors rather than the more efficient reciprocating compressors because of their very high reliability. The root problem is that the He market is so small compared to Freon that it is difficult to get the vendor's R&D attention. One vendor has been working on this over the last few years; leading Fermi to replace their entire compressors system with more efficient rotors and the correct built-in volume ratio. The efficiency increased from 35 to 50%; i.e. a pay back period of less than 3 years permitting IHEM funding.

The second factor is the number of stages; multi stage systems with pressure ratios of 3 or less are much more efficient than 6 to 8 (or 15 used in very small systems and purifiers).

The national lab effort will not be true R&D or even fund R&D at the vendor, but will be a "Buy and Try" effort. One suggestion with high potential was for JLab to add a CHL third stage since their 5 Mw second stage is operating with a pressure ration of 8.

2. HTS power leads (FY94 recommendation)

HTS power leads can reduce the required refrigeration by as much as 25% for circular accelerator; this was identified by the FY94 Working Group. LHC has a major effort on HTS leads with contracts to 13 vendors. Fermi also has a small effort for both the Tevatron as well as the US LHC effort.

R&D THAT WILL HAPPEN ANYWAY

1. Short sample vs. dT optimizations for Nb_3Sn (FY94 recommendation)

As part of integrated design, we need to know how Nb_3Sn magnets perform at elevated temperatures. Since this is a standard part of magnet testing, the data will be availability in about 18 months when the first high field VLHC magnet is scheduled to be tested.

R&D THAT SHOULD BE FUNDED BY VLHC

1. Flow instabilities

A large number of different instability were discussed; McAshan provided a literature search (Attachment #1) of work done over the last forty years. The most important for VLHC due to the need for long string length are "Density Wave Instabilities". They have been observed in transfer lines at Fermi, JLab, and DESY (cavity) but have received almost no theoretical attention from the cryogenic groups. They have been experimental stabilized by a combination of inlet orifices and higher operating pressures. Density Wave Instabilities are a major issue if the density is varying by factor 3 or more (which includes cooldown of all projects). Fixing the problem after we start operating by throwing away efficiency is not the way to proceed for VLHC.

Numeric simulations follow by experimental verifications are needed on all these instability; it is also a very good way to maintain core competency.

2. Beam screens

In about another year the minimum R&D on the LHC 4.5 K magnet beam screens will be complete. At that point VLHC should pick up this effort, since LHC continuing effort is unlikely in light of their severe manpower shortages. R&D should include absorber materials, especially at 5 K, as well as chemical adsorption at low temperatures.

3. Cycle and efficiencies for sensible heat vs. latent heat systems

We should study sensible heat systems. Taking the heat as sensible heat in supercritical helium over a significant temperature range, such as 4.5 to 5.5 K provides system simplifications. We should do cycle designs since for most sensible heat systems we loose at least 5% in efficiency (25 vs. 30% at 4.5K). The BNL power transmission would be a good starting point for this effort. Again this will help to maintain core competency.

4. Magnetic bearing turbines (FY94 recommendation)

Highly reliable turbines that are easy to operate should be developed. Today, cryogenic turbines use either gas or oil as a bearing and also as a brake. In the future, turbines could be built with magnetic bearing and use regeneration as the brake, i.e., the same reliability as cold compressors.

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[4] M. McAshan and P. Mazur, "Cryogenic Systems for the High Field RLHC Study Case," p 316; contribution to the Snowmass 96 Proceedings.

ATTACHMENT #1

References; Latent Heat Systems (Preliminary)

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