SNS JLab Cryo Module Review Report

Oct 15, 16, 2003 review, Oct 29, 2003 report

Cavity and Module Production Status

0.0 Introduction

This review focused on the SNS cavity processing and module production. There has been lower than expected yield of qualified cavities from the vertical dewar tests, resulting in slower that expected production rate and less rate improvement from the learning curve than originally planned. The main bottleneck has been in the area of cavity processing with limitations due to cavity field emission, not in module assembly or final testing. The processing procedure was extensively reviewed and detailed recommendations are made. JLab presented a plan, schedule and cost impact for proceeding from this date. Comments and recommendations relative to the plan are made.

That said, JLab is to be commended on establishing the over all superconducting linac and cryogenic procurement and production in an efficient and timely manner. The cryomodule production line has been well established and successful. JLab should be commended for their substantial commitment to the SNS Project.

The gradient specification for medium beta (high beta) gradient at Q 5e9 is 10.0 MV/m (15.6 MV/m). Epeak at specification is 27 MV/m (33.4 MV/m) for Epeak/Eacc of 2.63 (2.14).

Summary of recommendations

1) There is a basic need to try to understand and rectify the problem source, rather than live with it. JLab should concentrate effort on improving the yield of acceptable cavities in the vertical dewar test. To this end they should implement improved procedures as reviewed of Mammosser's Production Sequence. (See Attachment A). These procedure improvements are not R&D activities, but adaptation of proven techniques. SNS and JLab should not be satisfied with the marginal test yield and should try to extensively reduce the field emission problem. This will lead to a better linac and reduced processing time on the overall time schedule.

2) All appropriate talent, who are not already engaged should be brought to bear and be enlisted to work on the problem. An increase in general string production manpower is not warranted or desirable until yield has improved. Other interfering activities that lead to interruption of the SNS cavity production sequence should be minimized until reasonable SNS success rate is achieved.

3) EP development effort should be minimized so as not to interfere with production until stable results in standard processing are reached.

4) The cavity production status should be reviewed within 3 months. At this time cavity yield, manpower and cost/schedule can be reevaluated.

Response to the Charge and Additional Issues

In what follows the Charge and additional issues or questions raised are indicated in italics.

Charge

Comment on:

1.0 Technical

1.1. Production status

1.1.1 Cavity/Module Status

The total number of cavities required for SNS is 81 for 11 medium beta 3 cavity modules and 12 high beta 4 cavity modules. To date 21 medium beta cavities have been qualified for module assembly out of ~50 vertical dewar tests. Six medium beta modules (M1-6) have been completed, and 8 out of the 9 cavities in three modules (M1,2,3) tested above specification. One cavity did not complete its gradient test at 5e9 Q because of klystron failure. Other tests of this cavity showed good performance. Initial tests of cavity MB10 in module M5 showed marginal performance; tests were interrupted by another klystron failure. Further tests on this module will be carried out the week of Oct 20.

Most of the testing has been carried out on the medium beta cavities, however out of 7 vertical dewar tests on high beta cavities (5 EP, 2 BCP) only one EP production, one BCP production, and one EP prototype cavity have passed the specification.

Production status and throughput are limited by the low yield (64%) of acceptable cavity performance, after initial cavity preparation, in 1st cavity tests in the vertical dewar tests. From a set of ~24 cavities, 50 process/reprocess and vertical tests were needed to yield ~ 22 cavities acceptable for module installation. Only ~16 of these cavities passed on their first test. The situation is further confused by the higher performance obtained in the module tests of the small number of cavities (8 out of 9) that have been tested so far. Even so direct correlation between vertical and module test is not necessarily expected as cavities are re-etched and rinsed between these tests, and the vertical dewar test is carried out in cw mode operation, while the module test is pulsed.

There have been a number of difficulties and failures to date that have been overcome:

- Biological Contamination of the Ultra Pure Water
- High pressure rinse system pump failure
- 1MW RF system failures
- Al vacuum seals leaks
- Cold tuner failure cold
- HOM notch filter power dissipation
- Hurricane

JLab has tried to improve vertical test performance, but without great success.

Conclusion

The cavities appear to have low and erratic thresholds for field emission that results in low Q at specified gradient. No limitation by breakdown / material impurities was found so far.

It would appear probable that the poor qualifying results may be due to preparation process rather than cavity related. The need to reprocess and retest is slowing down testing and module output and increasing manpower required.

There is a basic need to try to understand and rectify the problem source, rather than live with it.

1.1.2 Manpower and Schedule Status

The end game plan for the SNS project was discussed by N. Holtkamp. The Integrated Project Schedule (IPS) Early Finish Date (project complete) has been shifted 3 months to March 06 in order to better match the BA funding profile. (The DOE Project Completion Date remains June 30, 06). The SRF linac start commissioning date is now 3/05. Modules can not be tested at ORNL before ~May, June 04, as testing can not start until cryoplant commissioning has been completed.

Total JLab SNS FTE count in FY03 was 57. Of this total, cavity production (to string assembly in clean room) had ~12.6 FTE (not counting SNS personnel) and has been able to produce 3 cavities/month at specification goal, assuming yield of 50%. (In addition the EP effort is about 2FTE's including 1 FTE from SNS.)

Cryomodule assembly appears to be on track and consistent with manpower (~12FTE's) and schedule if strings are available. There is a cost risk associated with the "standing army" if strings are not available. The planned rate is 1.25 modules /month. The present rate is about 9 weeks assembly time per module per production line. With 2 lines this amounts to ~ 0.9 modules assembled per month. It is expected that there will be further learning curve gain.

Module testing requires 4.7 shift weeks/module, and 0.3 FTEyears/module (ie ~3 FTE's). There can be some time saving in going to a reduced test plan as presented in the review.

The overall future schedule calls for about a 15 month duration for cavity processing and string assembly. With 60 cavities still to qualify, a rate of 4-5 cavities per month is necessary.

In order to reach that number Rode presented a "baseline" plan and an "alternate" plan for FY04 and 05. The conservative premise for these plans is that the yield will not increase. JLab strongly prefers the "baseline" plan.

The "baseline" plan presented is to increase cavity production manpower to 5/3*12=~20FTE (total with overtime) and to go to 7 day/week cavity testing. This increase of 8 FTE's would essentially use all trained JLab manpower in this area. Planned

module production rate would be one/16days or 1.25/month. The cost variance for FY04 and FY05 they expect would be ~ 1.5M$ (100k$/month).

The "alternate" plan would keep production manpower at the present level and rate of ~0.8-0.9 modules/month and consequently stretch the schedule 6 months to July 05 and increase cost an additional 0.6M$.

The present accumulated variance to date is ~2.4M$. The JLab Budget BAC total is 60.1 M$, CryoModules 32.3 M$ without contingency.

Conclusion

The underlying premise that vertical dewar yield will not increase does not address the fundamental issue that there appears to be a process procedure problem that results in field emission limitation at low gradients. It is important that every attempt be made to rectify this problem as it will affect the final performance of the srf linac.

Increasing the work force before the problem is corrected does not seem wise as it may only result in faster production of field emitting cavities and may add another degree of confusion and a temporary reduced cavity throughput through the addition of personnel and training. However, the committee did not hear how the facility was shared between SNS work and other activities. Every attempt should be to reduce confusion and interference from other activities, even if this means restricting them until stable SNS production is reached.

If the 50% yield (3 cavities out of 6 tests) could be increased to >80% or 5 out of 6 tests, the manpower could remain approximately at its present level and the production rate met.

The present cost variance for cryomodules appears to be ~100 k$/month. It is unclear how increasing the string work force from 12 to 20 FTEs can be supported at the same variance of 100k$/month. (Earned value of high beta modules is ~4/3 of medium beta. This may help if labor efficiencies related to the longer strings can be achieved.) (Rode provided material that indicates that additional trained manpower is available.)

1.2 Procedures and possible improvements

Considerable time was spent during the review in going over with John Mammosser the cavity processing procedures leading up to vertical dewar tests and string assembly. John is to be commended on his preparation of detailed procedure steps that could be reviewed in detail. He now has an edited list of steps where differences with DESY procedures are noted. (Attachment A)

The step by step review of the cavity processing procedures revealed a number of areas where procedures differ from those at DESY. Modification toward DESY procedures, especially in rinsing procedures and scrutiny of parts assembly for test should be initiated.

We recommend concentration on obtaining improved vertical tests and acceptance yields by implementing the outlined changes in processing procedures.
We recommend that the production line not be stopped but there be changes in procedures as discussed below. These changes can be implemented as production proceeds.

Technical Issue- List technical changes as advised by committee. Provide a list of procedure changes to identify the infrastructure improvements that are necessary to improve cavity yield.
The list of procedure differences and improvement areas includes:

- Ultra sound and rinse before heat treatment
- Rinsing duration determined on resistivity instead on time base
- Seal cavities better during tank welding
- BCP - increase to 100 microns, less than 10 gm/lit Nb concentration in acid
- Significantly improve rinsing after BCP, obtain18 Mohm-cm water before surface drains during hand over to class 100 area
- HPR-increase rinse time, and modify procedure for one pass down and intermediate draining
- Modify nozzle geometry
- Improved drying procedures
- Dry assembly as much as possible
- Vertical test stand- either clean the stand vacuum system or do with sealed cavity

Also see detailed list in Attach A.

Additional comments-
Most of the recommended procedure changes can be done rather easily. As much as possible they should be done in parallel as soon as possible. It should be stressed that these are not R&D activities but rather improvement and adaptation as much as possible of proven successful techniques.

There could be advantage to setting aside a "test" cavity, one that has proven superior test results. If processing difficulties arise in the future this cavity could be reprocessed to "certify" (from the last to first steps) the processing performance.

There was discussion of the adequacy of the high pressure rinse nozzles for the large SNS cavities. As delivery of commercial nozzles can take some time, it would be best if new nozzles with a different orifice were fabricated at JLab if timely alternate solutions are not found.

Another suggestion discussed was to re-rinse a cavity showing strong field emission but without applying higher RF power so as to avoid burning in emitters. This procedure has shown success at DESY.

DESY results-
Attachment B summarizes results from TESLA 3rd and 2nd production series. Data is from the 1st RF power step by step "rise test" of cavities after their 1st BCP processing

cycle, and without any rf processing. TTF Epeak/Eacc =2.0 and acceptance is set at Eacc 25 MV/m, Q5e9. Thus TTF Epeak acceptance is 50MV/m, whereas SNS Epeak acceptance is 27MV/m (33MV/m) for medium (high) beta. Fig 2 in Attach C indicates that 15 out of 16 cavities in 3rd production would have passed both SNS specifications. The success rate would have been much lower from the earlier 2nd production series. Out of 8 cavities, one would not have passed the medium beta spec, and 2 other would have been marginal for medium beta and would not have passed high beta. It should be noted that SNS cavity area is about 75% (100%) greater in medium (high) beta cavities than in Tesla cavities. (The area of medium (high) beta cavities is 1.4msq (1.7msq) vs. 0.8msq for TESLA.)

Technical Issue-Advise on EP program continuation.
We recommend that the EP activity be given minimum priority until improved vertical dewar testing has been accomplished.

There is little point in preparing cavities by EP if there is doubt in the following rinsing and test preparation. It will be difficult to commission the new set up and attribute any performance inadequacies to one or the other process. However, if it was not a distraction from the main problem of cavity test performance, it would be valuable if development on the EP process could proceed at some low level.

At this time there is a real issue as to getting acceptable yield on the high beta cavities as well as the medium beta ones. BCP should be adequate for high beta requirements, as indicated from prototype test results.

1.3 Module Testing plans
Technical Issue- Changes to the test program for SNS cavities given that 12 cryomodules tests are funded.
The present testing plan calls for testing of a total of 12 modules (out of 23) at JLab.
A plan is proposed by Rode (Attachment C) that reflects the overall testing of modules, either at JLab or Oakridge.

It is imperative that CM 4, 5, 6 ,7, and 1st hi beta be tested as soon as possible in order to ascertain their cavity performance and correlation with vertical tests.

There is at this time no good correlation between cavity vertical tests and results obtained in the module. There is an additional etching and HPR before cavity assembly in the module, resulting in an expected loss of correlation between the two sets of test results. (Cavities for module assembly are (may be?) dried horizontally. This may also explain some of the better results in module tests.)

With this in mind, it will be important that tests of all modules (either in the module test area or at Oakridge) be carried out as soon as possible. The time at which tests can start at Oakridge is dependent on the commissioning of the cryoplant and may not be able to start before mid 2004.

Attachment C (provided by Rode after the review) outlines an integrated module test sequence. It shows tests at JLab of MB05-11 and HB01-02 (MVB01-03 have been tested). MB05-07 should be tested at JLab within the next 3 months. On the schedule there is only a one month wait between the last test at JLab and testing at ORNL of modules untested at JLab. MB04, presently in storage, would not get tested till July 04. If there is a break in the JLab test schedule perhaps this can be tested earlier.

This plan seems reasonable. The cost impact of this plan needs to be evaluated if it has not been. When more module test results are available these plans should be reviewed. (We recommend this be included in a review of the cavity yield to take place in not longer than three months.)

There was discussion of the possibility of acceptance of cavities that did not meet the "average " specification. There is an average spec and a minimum spec. The minimum spec is about 1 MV/m (3 MV/m) below the average for medium (high) beta cavities. Presently, the average spec is applied to vertical dewar tests and the minimum spec is applied to modules. As Q is reflected in cryo load, the average Q of all cavities will determine the load, so there can be some flexibility in the final acceptance of individual cavities and modules and their position in the linac. However strong field emission is undesirable in itself. We believe that module acceptance should be negotiated on a case by case basis between JLab and ORNL. It does not seem prudent to consider lowering the acceptance level in the vertical dewar tests.

1.4 Provide input on tests that are necessary to support an increase in the production efficiency

Vertical dewar tests test for cavity limiting defects and the viability of process procedures. Without them there is no assurance that cavity module preparation will be acceptable. Module tests test for "installed " performance. These tests are the first look at the performance quality of the linac. Neither should be short changed till reproducible, consistent and acceptable results are achieved.

1.5 QC/QA programs on infrastructure and existing procedures

The QC/QA program appears well developed and adequate. However it cannot in its-self result in higher yield of cavity first tests without identification of the problem(s).

2 Management, 3 Cost and Schedule

Below we address issues of management , cost and schedule as requested in the charge. Some of the information is redundant with that above. Some committee members would like to stress that they look at these issues as coming after the actual solving of the technical problems and that the focus of the report should be on addressing the problems as outlined in Section 1.

2.0 Management

Management Issue- The learning curve is a viable assumption that was used from the very beginning to make the feasibility case for SNS to go superconducting.

JLab should not back off from cavity processing improvement.
Cavity success rate now ~3/m, with ~5.5 tests/m. Needs to be 5/m to match 1.25m/m
We believe the best way to optimize production is to improve success rate. This will take a concerted laboratory effort to improve processing to get to >80% success rate on first test. This does not necessarily require more workers at least till processing is improved.

Management Issue- The present cost variance SNS has to cover and finish the work through FY04. Recommend an approach.
Present accumulated cost variance should be resolved between JLab and ORNL. We expect that there will be some additional variance till the processing success rate has improved. A plan should be developed to aggressively minimize the additional variance. This plan should be reviewed in not later than 3 months.

Management Issue- Is the lab commitment to focus 100% on SNS necessary and the only way to efficiently finish SNS cryomodule production and meet the SNS commissioning schedule? Does all the talent in the lab needs to be brought in to solve the present efficiency/yield problem?

All appropriate talent should be brought to bear. Experienced personnel who are not already engaged should be enlisted, who are not already engaged. Building up the work force at this time does not seem appropriate till the processing has been improved. The status and progress should be reviewed within 3 months as noted above.

We believe that intermingling of other cavity processing with the processing of SNS cavities makes for further confusion and difficulty of establishing repetitive production. Other processing work that interferes should be restricted until SNS yield has improved.

3.0 Schedule and cost control:

3.1 Reduction/increase in testing plans and if so where

Testing as presently planned of both vertical dewar cavity tests and module tests should continue as planned. Elimination of module testing should not be initiated until satisfactory and consistent test results are achieved or till tests can be carried out at ORNL. (See 1.3 above)

Drury outlined a plan for reduced module testing (now 4.7 shift weeks/module) that reduced some of the repetitive measurements (mechanical and piezo tuner, Lorentz force) and had a savings of 100 out of 500 man-hr per module. This reduced plan seemed reasonable.

3.2 Present manpower loading. Improvements in efficiency. Possibilities of reduction in work force to minimize future contingency draws

This can only be considered when stable and adequate cavity yield is achieved. It is unlikely that reduced work force in the cryomodule production area will be desirable.

3.3 Discussion of offsets possible out of other areas

This was not discussed in detail. See 3.4 below.

3.4 Transfer of work scope to ASD/ORNL

Rode addressed a transfer of work plan that seems reasonable.

Delayen reported that there was considerable data recorded in the database that should be looked at and could well contain clues to the erratic testing results. This is an area where Oakridge personnel might be able to work with Delayen at developing a plan for analyzing the available data and upon review proceeding with analysis of potential high payoff areas. Treatment modifications suggested by data analysis should not be considered until processing procedures suggested by the committee have been attempted.

Possible areas - test analysis
Horizontal drying
VTA and cryomodule differences
Bad (worst) cavities (like#13) seem to get better, i.e. not statistical (Rode has a plot that refutes this.)
Correlation with rinsing length, etc

Cost/Schedule Issue- Is the manpower adequate? Should more/less people work on SNS
The mix of manpower ... For maximum probability of success more experienced personnel trained should be brought into the effort to improve the processing. Overall manpower should not be increased till more efficient processing allows for increased production.

Cost/Schedule Issue- Is the proposed approach from JLab to meet schedule viable? (Put more workers on it and live with the 60% yield rate)
We do not think the proposed JLab approach is viable. We believe it will not result in optimum cost or more importantly linac performance. We believe additional near term effort should be put on processing improvements to increase the yield.

Cost/Schedule Issue- Is the cost extrapolation viable?
The cost extrapolation is difficult to understand as discussed in 1.1.2. However as we believe the focus should be on improved yield not on status quo. The cost extrapolation should be reviewed within 3 months. Even so all cost extrapolation models would appear to be will within a 20% contingence. There may be schedule impact as well if yield cannot be increased.

Attachments
Att A Mammosser Production Sequence
Att B Matheisen DESY Tests
Att C Rode Test Schedule
Att D Agenda
Att E Holtkamp Charge Letter

Charge

Please comment on
Technical

- The production status
- Procedures and possible improvements thereof
- QC/QA programs on infrastructure and existing procedures
- Provide input to tests that are necessary to support an increase in the production efficiency
- The testing plans

Schedule and Cost control

- Reduction (Increase) in testing plans and, if so where?
- Present manpower loading. Improvements in efficiency. Possibilities of reduction in work force to minimize future contingency draws
- Discussion of offsets possible out of other areas
- Transfer of work scope to ASD/ORNL

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