Committee Report
STAR Time Projection Chamber Outer Field Cage
Preliminary Design Review
February 10, 1994

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Introduction

Members of the STAR TPC design team made presentations on the status of the Outer Field Cage (OFC) design and prototyping effort to a Preliminary Design Review (PDR) Committee at LBL the morning of February 10, 1994. The committee, composed of individuals with experience relevant to the design and fabrication of large, high-voltage structures, discussed the information presented during the afternoon and then held a close-out session with the OFC design team. The committee charge, review agenda, presentation materials and action items can be found in the OFC PDR binder in the STAR Project Office. This review represented the second formal technical review of the TPC OFC, and the first since the decision was made to design for an operating voltage of 90kV.

Executive Summary

The committee found the design approach appropriate to meet the requirements of holding off 90kV with a minimum mass structure. There are some questions which must be answered before a clear understanding of the voltage holding capacity of the OFC can be claimed. The most important is, "What is the operating radiation environment of RHIC?" Additional suggestions for improving the voltage holding "factor of safety" are included in this report and in the action items.

The committee felt that a more complete test plan should be written for both the 5-cm prototype and the production OFC. Without clearly defining the test goals, the group risks accepting any results as adequate, which could lead to a minimal safety factor. The possibility that a breakdown will cause a deteriorating condition increases as the stored energy increases in these large prototypes or production field cages. Test procedures should be further defined to prevent such breakdowns.

There are several key analytical results that support the design. Each of these should be documented and independently verified.

The schedule presented during the review seems reasonable but needs to be supported with a more detailed analysis of the tasks that reflect the fabrication and assembly logic.

Critical Issues/Findings

The committee feels that the design concepts are sound, but some details still need to be addressed in the detail design phase. Some specific recommendations follow.

Several effects on the field quality were considered in the analyses to date (z displacement of one end of the OFC, and resistor chain tolerance). It was felt however, that to assure the field cage design meets the $\int \frac{Er}{Ez} dz < 0.4$ mm electric field quality requirements, all the potential effects must be considered.

A test plan for the 5-cm Prototype should be documented along with clearly defined goals for voltage holding. It is very important to ensure that if breakdowns occur at or around 90 kV, they do not cause a deteriorating condition. That is, the stored energy in the inter-electrodes and the stray capacitance to ground is not sufficient to cause damage to the surfaces.

There is a need to better understand the RHIC operating radiation environment so that this environment can be more appropriately modeled during the prototype tests. Without clear understanding of the actual RHIC environment, a clear understanding of the actual operating safety margin is not possible.

Since the OFC structural design is being pushed hard for maximum stiffness and minimum mass, the committee feels that an independent verification of the analyses should be undertaken soon.

The committee also recommends that the design of the high-voltage safety interlock system be undertaken soon, and that high-voltage feed issues (outside the OFC volume) be addressed.

In reviewing the schedule and fabrication plans, the committee recommends that the plans for fabrication tooling be better integrated into the schedule, and that tasks and critical process items be specifically defined. The committee feels that by developing a more detailed Pert (logic) chart, it may be possible to discover critical problem areas (i.e. procured items needed early in the fabrication process.) When the above chart is complete and understood, a procurement plan should be drafted and a meeting should be held with Purchasing (Tom Beales, et al) to finalize the procurement strategy.

Requirements/Scope

The requirements of the final OFC unit seem to be well understood in terms of the amount of material in front of the calorimeter, the operating HV for the different gases, and the field quality for adequate momentum resolution. Several effects on the field quality were considered (z displacement of one end of the OFC, resistor chain tolerance), and these do not seem to present any problem. The criteria is that $\int \frac{Er}{Ez} dz$ be less than 0.4 mm for the He-Ethane gas. Many other effects (all mechanical tolerances, various sources of parallel resistance to the main resistor chain, etc.) must be considered and it must be shown that the "sum" of all probable effects on the field quality give $\int \frac{Er}{Ez} dz < 0.4$.

The requirements of the 5-cm prototype are not as well defined. In particular, the following questions need to be studied and answered:

- *What is the minimum acceptable lifetime at 100 kV that shows that the final design is adequate?*
- *What is the minimum acceptable breakdown voltage for the prototype that will show that the final design is adequate?*
- *What is the safety factor that will be applied to the test results to determine the safe operating voltage of the final unit?*

Mechanical Design & Fabrication

Good progress is being made on the technical aspects of the mechanical design and fabrication. Work is moving ahead in a logical and well-planned manner. There are several key analytical results that support the design. Each of these should be documented and independently checked and verified. All assumptions made in the analysis seem reasonable. An obvious mechanical concern is the inability of the field cage cylinder to support concentrated loads or external pressure. If a person ever has to enter this cylinder, protective measures will need to be employed. Temperature variations should be considered throughout manufacture, assembly and shipping. Details of components, including tolerance considerations and lead-in features on the end rings, should be reviewed at a later date.

Electrical Design/Analysis

The most important issue related to the STAR TPC field cage design is the voltage breakdown limit for the proposed insulating gas. A number of

experiments have already been performed to test the safety factors and breakdown effects of the present design. These breakdown experiments indicate that operation at 90 kV may have adequate safety factors. An appropriate Paschen's curve shows breakdown at 150 kV, but 130 to 140 kV may be achieved. The next test with the 5-cm gap should be definitive. It is very important to ensure that if breakdowns occur at 90 kV, they do not cause a deteriorating condition: that is, the stored energy in the inter-electrodes and the stray capacitance to ground is not sufficient to cause damage to the surfaces and breaks down at lower and lower voltages. It appears from tests already performed that this is not the case. The tests should duplicate closely the actual energy in the full-size field cage. (See calculation in appendix A for estimate of energy stored.) It is also essential to know if the radiation bursts from RHIC are adequately represented by the radiation source tests. If they are, and no damage occurs after breakdowns, then the safety margins can be considered adequate if the breakdowns are infrequent. As planned, an isolation resistor should be used to de-couple the cable and power supply capacitances from the breakdown.

The grading resistors power dissipation should be one-half or less that of the actual rating for 0.1% accuracy, and will probably need to be made of a metal film.

It appears that the total energy will be less than 12 Joules which is considered close to the threshold of damage by Hopkins & Baker. The next test with the 5-cm gap spacing should be a definitive test of the safety factors.

R&D and Prototyping

The R&D completed to date, and the additional prototyping planned, represent an excellent program for the TPC OFC. Still, various questions and suggestions were made during the presentations that warrant further work. Specific suggestions are included in the action items.

In the HV area, there are no generally accepted safety factors. Good design practice may call for a factor of two between the breakdown and operating voltages. When this practice is applied, actual measurements will nearly always yield results something less than a factor of 2. Recognizing that the tests themselves can be damaging, it is possible to look at the effects of improvements on smaller scale subassemblies or on the real thing with a gas that has lower breakdown strength. In all of this, it should be remembered that the 90 kV requirement is not final, and that even the 30 kV solution with P-10 remains a possibility. On the other hand, V>90 kV should be even better (V=voltage in the field cage).

Fortunately, most of the interesting mechanical and electrical effects can be easily measured. Use due care to model the real environmental conditions, especially surface effects such as moisture, or lack thereof.

Safety Issues

It appears that the total stored energy in the OFC will be less than 12 Joules which is considered close to the threshold of damage by Hopkins & Baker. Five Joules was considered by Hopkins & Baker as the damage threshold for fine grids as in neutral beam sources. In other words, a breakdown depositing greater than 5 Joules could cause damage to the grids. The situation for the copper stripes on Kapton are very different and only a real test (as planned) can establish the damage threshold. If no damage or deterioration in voltage holding occurs with arcing then the "factor of two" standard can be relaxed.

Actual mechanical damage depends on physical size and thickness of the surface where breakdown occurs and the electrical damping or limiting of the discharge currents. Hence, it is desirable to isolate the various regions where electro-static energy is stored, for example by using resistive high-voltage cable or by placing high-voltage resistors along the cable. For electrical safety there is a dividing line at present classifications of 5 Joules. It may be desirable to attempt to reach this goal by isolating each half of the OFC (large resistance between the two), and by isolating the cables bringing power from the supply from the OFC. This will also reduce the risk to human safety to levels significantly below those known to have caused human fatality.

The committee recommends that the design of the high-voltage safety interlock system be undertaken soon, and that high-voltage feed issues (outside the OFC volume) be addressed.

Schedule

The schedule presented during the review needs to be supported by a more detailed analysis of the tasks that reflect the fabrication and assembly logic. The activities for fabrication have been identified so the required information is available. A procurement plan should be developed, communicated to the LBL Purchasing Department and included in the schedule. The committee recommends avoiding sole source procurements. If they are unavoidable, allow a significant time for the placement of these orders. Potential vendors for the large components that are to be machined should be identified at an early date.

Appendix A - Calculation of Stored Energy

Capacitance of cylinders C=2