Committee Report
STAR Time Projection Chamber Outer Field Cage
Final Design Review
December 8, 1994

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Introduction:

Members of the STAR TPC design team made presentations on the final Outer Field Cage (OFC) design, and the results of the prototyping R&D effort to a Final Design Review Committee at LBL on December 8, 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 FDR binder in the STAR Project Office. Many of the comments or issues are presented in detail in the action items. The action items should be considered an appendix to this report.

This review represented the third formal technical review of the TPC OFC, and the second since the decision was made to design an operating voltage of 85kV.

Executive Summary:

The committee found the OFC detailed design to be appropriate to meet the requirements of holding off 85kV with a minimum mass structure if C_2F_6 is used as the insulating gas, and a few additional qualifying tests are completed. The experimental results with C_2F_6 lead the committee to believe that breakdowns at 85kV operation would be very rare (further tests should be conducted to add to the statistics). Other experimental results lead the committee to the conclusion that if breakdowns do occur, they would **not** cause a deteriorating condition (lower voltages causing breakdown). The committee concludes that the electrical aspects of the outer field cage design are sufficient.

A question that remains from the February PDR is, "What is the operating radiation environment of RHIC?" Several tests have been done in radiation environments at the 88-inch Cyclotron, but how do these compare with the environment in a RHIC beam fault?

Also, at the last PDR, the committee stated, "Since the OFC structural design is being pushed hard for maximum stiffness and minimum mass, the committee feels that an independent verification of the analysis should be undertaken soon." This statement still applies; an independent and more detailed review of the analysis and results is crucial.

The tooling, winding and assembly procedures have been well thought out and developed so that production can continue.

Major procurements are under control, and the schedule has now been developed in sufficient detail to identify the critical path. It would be unfortunate if resource limitations (insufficient technician staff) were to restrict daily assembly hours on the critical path activities. The OFC completion date of February 1996 does not include any float time. If this date is critical to the project, every effort should be made to incorporate some contingency plans to recoup time if problems arise in the fabrication phase.

The safety issues raised at the February PDR were addressed and answered at the FDR. Tests were made at full energy (20 Joules) on the OFC prototypes, and after several arc-downs the voltage hold-off (as mentioned above) did not deteriorate.

Critical Issues/Findings:

The committee feels that the design concepts are sound, but some issues still need to be addressed before beginning the winding phase. These issues are discussed below.

1. The committee heard results from the many R&D tests and analyses performed, but, from the presentation, it was hard to determine if a thorough and comprehensive plan had been used consistently. The committee felt that there are still some key tests that need to be done on both the drift and insulating gases and their interactions with each other (C_2F_6 poisoning), and further tests must be completed with C_2F_6 at or near breakdown where there are only marginal statistics and "canary cage" tests on construction material samples (the sticky side of Kapton tape). These tests should be completed before initiating construction of the field cages. It may be beneficial to organize and outline the tests completed to date, and review them from a "big picture" perspective for completeness and consistency.

   The following two issues were raised in the PDR report of last February and are repeated here.

2. There is a need to better understand the RHIC operating radiation environment so that a beam fault safety margin can be calculated. Without a clear understanding of the actual RHIC environment, a clear understanding of the actual operating safety margin is not possible.

3. 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.

Safety Issues:

The safety issues raised at the February PDR were addressed and answered at the FDR. Tests were made at full energy (20 Joules) on the OFC prototypes and after several arc-downs the voltage hold-off did not deteriorate. Even if ionizing radiation causes breakdowns in the high voltage (doubtful), there will be no detrimental effects except for the loss of some data. Personnel safety issues can be addressed simply by following LBL PUB 3000 or appropriate BNL guidelines. It is understood that the High Voltage Power Supply will be interlocked so the HV cannot be made active when the OFC is accessible.

Physics Requirements:

The requirements on the electric field uniformity seem to be well understood. Contributions to field non-uniformity due to equipotential strip placement, resistor value error, resistor value stability, trace-to-trace resistance and end cap deflection were all considered, and appear to be small enough for operation with P-10 gas in the TPC. It was not clear if they would be small enough for operation with He-Ethane gas.

It was also not clear what the specifications are on the allowable C_2F_6 contamination of the He-Ethane gas, and whether the specifications could be met.

Mechanical Design:

Progress has been made developing the mechanical design for the Field Cage and Gas Vessel. As found at the PDR, critical analytical results should be reviewed by a second person as a final check. Other concerns from the PDR appear to have been taken care of.

Specifications for the TPC gas systems (drift gas and insulating gas) need to be clearly documented and communicated to the designers of these systems. These specifications should include all credible operating conditions.

Electrical Design/Analysis:

Voltage grading has been achieved to better than 0.1% by "selecting" metal film resistors. Deviation in voltage can occur due to temperature changes and due to some resistors displaying a voltage coefficient. First, the temperature coefficient of metal film is low, and even if there were temperature changes, as long as it occurs uniformly, the voltage grading will not change. The voltage coefficient has also been considered, since for metal films below 500V, each is quite small. The connection between the high voltage cable and the artwork needs some further consideration. The point of contact is not well-defined. If the cable has semi-conductive shrink tubing over it, contact with the artwork may not be necessary if the grading is sufficiently uniform along its length. The connecting pins that bias the inside portion of the artwork should be reliable if the square corners cut into the material. Since there is no current flow, even a poor contact (one with some resistance) would work. However, if possible, for insured reliability over the lifetime of the detector, a solder joint should be considered.

The resistance of the high voltage cable center conductor should be checked to ensure that it will absorb its own stray energy and that of the power supply.

The voltage holding tests of the prototype indicate that operation at 85kV should be reliable. Even if an occasional breakdown was to occur at the full energy, there exists a condition of non-deterioration. Therefore, the voltage breakdown does not occur at lower and lower voltages.

Operating levels are typically chosen 50% below the self-breaking points when ionizing radiation is present, because the effect is always to lower the breakdown voltage. In this case, if the tests at the 88-inch Cyclotron duplicate the potential RHIC environment, then there seem to be sufficient safety factors. Since an occasional spark does not cause a worsening condition, but rather a simple loss of data during that time, safety factors can be lower.

Much of the progress has been made since the February review. All the previous electrical issues were addressed and resolved. The degree to which they were resolved for safety factors can be subject to individual judgment. The committee feels that further testing of breakdown at full or even greater energy should be done, and possibly some conditioning could lead to greater safety margins.

Nonetheless, it has been established that breakdowns at 85kV operation would be rare, and if they do occur, will not cause a deteriorating condition. Therefore, the committee concludes that the electrical aspects of the outer field cage design are adequate.

Tooling, Fabrication & Assembly:

The tooling, winding and assembly procedures have been well conceived and developed to the point where production can continue.

R&D and Prototyping:

A good program of OFC R&D was described, mainly involving tests of the OFC Prototype with the 5-cm gas gap insulator.

The tests with 100% nitrogen as the insulating gas indicate that this gas is adequate for operation at 30kV (with P-10 gas in the TPC), since the short-term breakdown voltages were in the range of 85-115kV and it easily sustained more than a 25% over-voltage for a week without sparking down. Nitrogen is not adequate for operation at 85kV (with He-Ethane gas in the TPC), because the prototype could not sustain a 25% over-voltage (106kV) for a week without sparking down.

It is encouraging that C_2F_6 at 109kV (28% over-voltage) worked for a week without any spark downs. However, this was one of only two tests with C_2F_6, and before pronouncing it adequate for operation at 85kV, it might be useful to repeat the test several more times (run it up and down to 109kV several times, leave it on for a week, and then repeat), and perhaps to do a test at a faster ramp rate.

The results of the ionization tests (using a proton beam) are excellent for both C_2F_6 (at 122kV) and nitrogen (at lower voltages). One should, however, estimate how the ionization seen in these tests compares with that from an accidental beam loss at RHIC.

Structural Analysis:

The presented structural analysis appeared to be thorough and the majority of the results logical. However, the committee highly recommends that an independent and more thorough review be undertaken by a qualified stress analyst. Mistakes, either input errors (slipped decimal in material properties), missed worst-case load conditions, or other simple errors could result in catastrophic failures. As a minimum, a complete review of the load cases, boundary conditions and results should be done.

A STAR Note summarizing the results of the engineering analyses of the OFC should also be generated, if this has not been done.

Schedule:

Major procurements are under control and the schedule has been developed in sufficient detail to identify the critical path. It would be unfortunate if resource limitations (insufficient technical staff) were to restrict daily assembly hours on the critical path activities. It is understood that only so much winding that can be done before the need to allow time for the epoxy to be set up, but since these activities are critical, second or extended shift operation should be seriously considered before the start of the fabrication phase. The OFC completion date in February 1996 does not include any float time. If this date is critical to the project, every effort should be made to incorporate some contingency plans to recoup time if problems arise during the fabrication phase.