NSTX-U OH Fault Review
Status Update 12 May 2015

Robert Ellis
Michael Bell, John DeLooper, Joel Hosea, Charles Neumeyer

PPPL External Review
MAY 2015

The review was held on Friday, 8 May

- The committee was formed and received its charge April 29 – May 1.
  - Address four concerns: root technical causes, root procedural causes, extent of condition, and the repair and design solutions.
- The committee was given an extensive documentation package prior to the review.
  - The committee met multiple times during the week of May 4-8, and members each spent more than a full additional day preparing for the review.
- The review committee completed its report May 12.
- The following slides contain highlights of the report.
- *The committee appreciates the all of the efforts by the project to collect and provide the documentation requested as well as the open, forthright communications by the team regarding the issues leading up to this event.*

Root technical cause: **Is the cause for the arc correctly identified and understood? Are there any other likely causes that should be more carefully considered? Are there contributing causes that also need to be addressed prior to implementing any repair or re-design work?**

- Primary findings:
  - The NSTX-U Team developed a plausible explanation of the fault based on a thorough examination of data and inspection of the affected areas.
  - The root technical cause appears to have been a "double ground fault" arising from contact between an uninsulated, inadequately restrained, braided ground strap and two of the water cooling fittings at the top of the OH solenoid.
- Observations:
  - The OH fault appears to have occurred due to the inadequate design and installation of the ground plane connection. As installed, the low-resistance braid encircled the solenoid completely. As a result, large toroidal currents were induced in the loop when the OH solenoid was pulsed resulting in large axial forces on the conductor which worked loose from its clamp.
  - Although the OH coil experienced unusual internal distributions of current and voltage during the fault, there is no evidence that any immediate damage resulted in the main body of the coil.

Root technical cause - continued

- Conclusion:
  - The committee concurs with the root technical cause explanation.
- Recommendations:
  - Determine the root cause of the ground plane connector design/installation errors. [Separate committee and QA procedure QA-019]
  - Continue to perform diagnostic electrical tests including repeat of coil resistance measurement, inductance measurement and impulse test to confirm that the turn-to-turn insulation is intact.
  - The design of the OH ground plane and its connections needs to undergo the standard PPPL design review, installation and inspection process, rather than relying on a “field fit-up.”

***Root procedural and process causes*: Are there any procedural or process lapses that contributed to the fault – either in design/installation or in machine operations/interlocks? Are there any procedural or process improvements that should be implemented?**

- We made a large number of findings, observations and recommendations in our response to this question. Details will appear in our report.
- Summary of findings:
  - It appears that the OH ground strap was not adequately specified before installation.
  - On April 24, three successive shots failed after the initial low power test shots. All failures were due to ground fault trips.
  - Staff in the control room did not examine time histories of ground currents and line voltages in the failed shots before proceeding to the next shot.
- Summary of observations:
  - The grounding system should have been defined in a drawing with a specific review of the system.
  - Despite three consecutive trips, it appears that staff did not believe the "indicators," did not examine the ground current signals, and proceeded to the fourth attempt without fully determining the cause of the trips.
  - The "stop work" rule was not invoked, even after three successive ground faults.

Root procedural and process causes - continued

- Summary of recommendations:
  - Revise operating procedures to require a full stop of operations upon a ground fault trip.
  - COEs should have a collection of MDS Scope pages set up to monitor critical operations and diagnose faults under operations procedure. The pages used should be optimized for the type of operation underway.
  - Determine NSTX-U project line of authority – who must approve proceeding with operations if causes of a ground fault have not been determined and resolved.
  - The Laboratory should determine whether the operators (COEs) report up to and through the NSTX-U organization rather than engineering.
  - The project needs to demonstrate how it will prevent this type of management control failure from recurring in the future.

***Extent of condition**:* Are there any other areas of NSTX-U, not yet identified, that might have been compromised by the fault, or be subject to similar defects? Are there any other similar weaknesses in the NSTX-U design, procedures, or processes that could lead to future difficulties?

- Findings:
  - The project has been consumed by the investigation and disassembly of the machine.
  - The project did not present a plan on how they were going to address this charge.
- Observations:
  - The review team noted that the OH Coil hipot level was not per the approved design documentation.
  - The review team noted the suggestion by J. Menard for a task force to conduct a walkdown of critical components of the machine. Joel Hosea has agreed to chair this task force.
  - The team has been made aware of a root cause analysis being conducted also, but results are not yet available.

Extent of condition - continued

- Recommendations:
  - The project needs to develop a comprehensive plan to address this charge question and be ready to present to the external review committee.
  - Form a small "task force" (with appropriate expertise) to walk down all the high-voltage parts of NSTX-U to determine anything out of the ordinary, or potentially questionable from an “high voltage hygiene” stand-point.
  - Evaluate other gaps, creepage paths, and insulation on other coils and appendages to see if problems exist similar to OH.
  - Analyze and document electrical effect of Aquapour and “dental floss” wires in gap between OH and TF.
  - Consider conducting a “blind spot” review, similar to the laboratory process
  - Complete root cause analysis and be prepared to present to external committee.

Repair and design solution: **Are the conceptual designs, repairs, and corrections identified by the NSTX-U team highly likely to avoid a recurrence of a similar fault? Are there other approaches that would be superior?**

- Findings:
  - Initial designs were presented to the committee.
  - Design involves three major areas: OH ground plane connection; grounding of OH compression system and improved OH cooling tube support brackets.

- Observations:
  - It appears that many of the changes are being "field designed" without the benefit of a high voltage engineer to assure the most efficient and effective approach.
  - None of the designs have gone through the PPPL design review process (CDR, PDR, FDR) yet.

Repair and design solution - continued

- Recommendations:
  - Ensure that ground plane connection does not form toroidal loop. If hose clamp approach is used to attach ground plane connector, ensure that type with thermal expansion spring is used. Demonstrate through measurement that the desired resistance is in the loop.
  - Consider conducting elastomer solution to ground plane electrical attachment to avoid use of flex copper braid. Provide documentation and drawings to justify and describe solution.
  - Consider scheme to monitor load impedance in PSRTC (and/or DCPS) to sense situations where coil has become degraded.
  - Review design of OH lead assembly: confirm cross sectional area of (+) and (-) conductors is equal; confirm that assumptions in design analysis are reflected in as-built configuration; confirm that insulation strength is good for at least 1.5 x Voh_hipot.