FROM: Arnold Kellman

TO: Mike Williams

SUBJECT: Report from NSTX-U Readiness Review Committee

DATE: 1/20/2015

OVERVIEW OF COMMITTEE ACTIVITY

A Readiness Review Committee met at PPPL December 9 – 11. The purpose of this review was to ensure that the commissioning and subsequent operation of the National Spherical Torus Experiment Upgrade (NSTX-U) could be performed in a safe and environmentally responsible manner. The specific charge questions, prepared by Mike Williams and the NSTX-U staff, are listed below. During the meeting, the committee heard presentations from the PPPL staff, interviewed various PPPL staff members, read procedures, viewed additional documentation, and toured the facility, including the torus hall to address the specific questions in the committee charter. A closeout presentation was made to Stewart Prager, Mike Williams and some of the NSTX-U staff by the committee on Thursday December 11.

CHARGE TO THE COMMITTEE

The following questions were taken from the NSTX-U Readiness to Operate Charter:

1. Do the approved NSTX-U Safety Assessment Document (SAD) and pending Safety Certificate adequately define the safe operating envelope for NSTX-U operations?

2. Are there clearly defined roles, responsibilities and training for NSTX-U operations personnel?

3. Are there clearly defined operating procedures that ensure that NSTX-U is commissioned and operated within the safe operating envelope defined by the NSTX-U Safety Assessment Document (SAD) and Safety Certificate (including off-normal events)?

4. Does the PPPL Activity Certification Committee (ACC) process ensure that configuration changes are adequately reviewed and appropriately documented in the NSTX-U Safety Assessment Document (SAD) and Safety Certificate?

5. Does the PPPL Activity Certification Committee (ACC) process, including approval to proceed by the PPPL ES&H Executive Board Chairperson, ensure that PPPL is indeed ready to begin NSTX-U operations?

6. At the time of project completion, will the NSTX Upgrade Project have delivered the Project Objectives as defined in Section 2.2 of the NSTX-U Project Execution Plan?

COMMITTEE MEMBERS

- Arnie Kellman, General Atomics, Chairperson
- Dragoslav Ciric, Culham Centre for Fusion Energy
- Kevin Freudenberg, Oak Ridge National Laboratory
- Tim Scoville, General Atomics
- Jim Irby, MIT Plasma Science and Fusion Center
- Dave Terry, MIT Plasma Science and Fusion Center
- Will Oren, Thomas Jefferson National Accelerator Facility
- Edward Lessard, Brookhaven National Laboratory
- Tom Todd, CCFE (Retired)

GENERAL FINDINGS

- The committee was impressed with the project and the evidence of continued high quality of workmanship and project management.
- The project is ~95% complete with the major production and assembly milestones and the highest risk items completed (CS, DCPS, NB Vessel modification, and NB2 installation) almost complete.
- The recent setback with the Aquapour removal was handled effectively through a combination of internal and external review panels. The expected impact on the physics plan will be minimal.
- Present status gives high confidence in successful completion of project and completion of CD4 in March.
- This committee was not asked to perform a typical Readiness Review. NSTX-U is not ready to resume operations of either the new beamline or plasma operation, as defined by ISTP-001.
    - 20 Project and 28 Operations Engineering Work Packages (EWPs) remain open.
    - 25 chits remain OPEN, 4 are CLOSED but not VERIFIED
    - Some official signed off drawings remain to be updated to “as-built” conditions.
    - PTPs are not yet updated
    - Personnel are not trained in new PTPs or new hardware, software, user interfaces
- The committee was asked to evaluate the SAD, whether the processes, procedures, and training protocols were in place to allow an assessment of readiness to be made by an internal review panel through the ACC process.
- Main conclusions include:
    - Additional work is needed on SAD and definition of Safety envelope.

- An extensive set of procedures exists to track completion of project, appropriately test all project upgrade elements and existing operational subsystems, and safely operate the device. However, test procedures are not yet updated and would benefit from improvements in quality and uniformity, e.g. allowable ranges in measurements should be included in PTPs, missing signatures, incomplete feedback. An improved focus of the QC/QA group on preparation and completion of procedures is recommended.
- Personnel clearly understand their roles (in some cases multiple) and responsibilities and training is excellent.
- The ACC process is well developed and manned by highly experienced staff members with a broad range of skills. High confidence exists that this process will properly assess Readiness to Operate, similar to what it has done in the past. However, procedural changes to ACC could further improve this well-established process.
- A great depth of institutional and detailed system knowledge exists in present staff. This contributes greatly to thoroughness of reviews and proper functioning and oversight of systems during operations and on-going system modifications and upgrades.
- No commissioning sequence up to full design parameters was presented. The committee recommends that a full commissioning plan be developed including verification of critical stress calculations.
- A potential problem is that since some of the very experienced staff hold more than one key role in the safety and operational management of the facility, there is a tendency to obviate the need for procedures and document trails regarding communication of emerging issues, plant status etc. between these roles.

ANSWERS TO CHARGE 1

Charge 1: Do the approved NSTX-U SAD and pending Safety Certificate adequately define the safe operating envelope for operations?

- Conditional yes, subject to Items Requiring Resolution

Committee members for Charge 1

- Will Oren (TJNAF), Edward Lessard (BNL)

Method of review:

- Document review, interviews, observations, presentations

Findings

- SAD still in draft
- SAD does not cover entire system's hazards (e.g., ODH in all relevant enclosures)
- Safety basis for the limits in the safety envelope were not described in SAD, but it is tied to the design parameters
- Pressurized water/stress issues in CS are not addressed in SAD/FMEA
- Software QA not addressed in QA section of SAD
- Operating organization structure and authorizations not addressed in SAD
- Linked references or appendices on N2, He and SF6 ODH calculations needed
- Linked references or appendices on radiation calculations needed
- SAD did not have a Maximum Credible Incident section (e.g., max D gas event, max direct radiation exposure, etc.)
- Engineered and administrative controls for non-standard industrial hazards not included in safety envelope (e.g., SIS/HIS operability, ODH protection system operability, etc.)
- Safety envelope does not include engineered and administrative control supports such as calibration frequency, testing frequency, configuration management for shield drawings
- No documented practice to measure and track integrated neutron fluence in safety envelope
- Assurance processes beyond QA (e.g., ACC) not described in the SAD

Comments

- Safety of rf system not adequately analyzed in SAD

Items Requiring Resolution Before ISTP

- Finalize SAD/SE
    - Address all non-standard industrial hazards (NSIH) for all enclosures and the basis for inclusion in SAD
    - Include sections that describe the assurance processes such as ACC
    - Include methodology to determine NSIH controls, and link NSIH controls to safety envelope
    - Identify tangible controls in safety envelope and their supports
    - Supporting safety related calculations need to be linked or appended to SAD

Items Requiring Resolution After ISTP

- The web based work control system should automatically forward work related to limits and controls in the safety envelope to the ACC

ANSWER TO CHARGE 3

Charge 3: Are there clearly defined operating procedures that ensure that NSTX is commissioned and operating within the safe operating envelope as defined by the SAD and Safety Certificate (including off-normal events)?

- Conditional yes, subject to Items Requiring Resolution

Committee members for Charge 3

- Will Oren (TJNAF), Edward Lessard (BNL)

Method of review:

- Document review, interviews, observations, presentations

Findings

- Non-standard industrial hazards that are controlled by engineered safety systems or administrative safety programs (NSIH controls) are not clearly identified in the Safety Assessment Document, e.g. SIS
- There are no tangible NSIH controls or NSIH control supports in the Safety Certificate
- There is no implementing procedure that ties responsible positions to credited controls in a Safety Certificate (e.g. identify responsible authority for assuring SIS is tested and operational).
- The limits in the Safety Certificate are not related to tangible controls that must be present during operations (e.g. what is tangible control for the lithium limit?)
- 19 NBI procedures have been expanded to include preparation for and safe operations of beam line 2
- Administrative procedure OP-NSTX-02, which is managed by the COE, lists the sub-systems and integrated system procedures for startup and operation of NSTX-U
- ACC is an assurance process/program that addresses technical ESH issues, reviews projects and modifications against the requirements in the safety envelope and assumptions in the SAD, and it performs readiness review activities. However, implementing procedures beyond the charge were not documented (e.g., procedure to request a review, procedure that describes the ACC activities, tracking of ACC issues to closure, records of the reviews, authorizations to operate the facility or to modify safety systems identified in the Safety Certificate).
- No discussion of purge procedures in SAD regarding D gas event and NSIH controls such as mandatory purge gas volume

- Work packages and controlled documents are readily retrievable; but not completely error free
- Some procedures out of date
- Software QA process not defined

Comments

- Findings indicate inadequate QA/QC on procedures, which is needed to assure they are implemented as intended

Items Requiring Resolution Before ISTP

- Administrative controls, such as procedures, are needed to stay within limits in safety envelope and need to be included in the safety envelope (e. g., procedures associated with limiting the LITER lithium capacity, boronization, neutron limit logging, and shield configuration management)
- Engineered controls such as minimum purge gas volumes, operability of SIS, etc. must be in Safety Envelope

Items Requiring Resolution After ISTP

- QA procedures/programs to regularly audit the thoroughness of use of installation, checkout and operations procedures needs to be established
- Develop auditable procedures for ACC process/program/authorization as it relates directly to implementation at NSTX
- Develop associated training for ACC process/program as it relates directly to implementation at NSTX

ADDENDUM TO CHARGE 3

Although not specifically asked to comment on machine protection in either Charge 1 or 3, it was felt by the committee that the role of the Digital Coil Protection System in the machine protection was significant enough to be worthy of comment.

Findings

- The hardware of the Digital Coil Protection System has a comprehensive redundancy and fail-safe architecture.
- The physical architecture employed modern low-cost 16-core chips in a standard rapidly exchangeable plug-in format, so that an adequate spares stock could easily and usefully be achieved.

Comments

- The system makes extensive use of a custom, made-to-order design of a multi-channel digitizer with multiplexed fiber-optic output, raising questions of design validation and lifetime, or Mean Time Between Failures. It would seem worthwhile to identify their failure modes in a simulation of their anticipated workload and working environment.

- In the longer term, the importance of the DCPS for machine protection surely warrants a comprehensive verification and validation process, not just for the early usage but evolving with the machine and the physics program and developing understanding of the potential threats to the tokamak assembly.

Items Requiring Resolution – URGENT

- To the extent that resources permit, develop a suitable testing plan, including a hardware simulator to challenge one or more examples of these digitizers, both inputs and outputs, over an extended period, in order to:
    - Prove longevity by burn-in (at least some hundreds of hours);
    - Identify repeated types of failure and redesign or acquire spares to suit the full set of such digitizers used in NSTX-U and its hot spares.

Items Requiring Resolution After ISTP

- Depending on the results of the simulator trials, acquire suitable spares and consider modifying the design to obviate any weaknesses identified.
- Continue monitoring the success or failure rate of the digitizers and adjust spares holdings, preventative maintenance planning, and design evolution accordingly.
    - Validation and verification of the coding within DCPS should be undertaken by suitable procedures such as by modeling (evolving with increasing physics understanding) and by cross-correlations with strain sensors, temperature sensors etc. on the load assembly.

ANSWER TO CHARGE 2

Charge 2: Are there clearly defined roles, responsibilities and training for NSTX-U operations personnel?

- Conditional yes, subject to Items Requiring Resolution

Committee members for Charge 2

- Jim Irby (MIT Plasma Science and Fusion Center), Dave Terry (MIT PSFC), Will Oren (TJNAF), Edward Lessard (BNL)

Method of review:

- Document review and interviews. Interviews included COE, Operations supervisor, Responsible Line Management, Cognizant Engineer, System Operator, and Entry Level engineer

Findings

- There is an outstanding culture of safety. All employees felt safe at PPPL and all commented on their own about how impressed they were with the safety program
- The people we interviewed gave very similar answers to the questions indicating there was a very good training in roles and responsibilities
- We found that all but one of the employees interviewed have been at PPPL for many years (> 20), and have extensive experience in many areas. Some concerns were mentioned about the need to train new people and transfer information as long-term people leave. Our one new employee indicated to us that this process is underway. Others said they were working with other engineers to make sure knowledge is not lost.
- Training requirements are documented and approval process is in place. All employees knew about this process, and how to use the online training tools.
- The situation regarding multiple-role position holder succession seems not to be recognized by some of the position-holders interviewed, whose response to queries on this issue was to debate which of the other near-retirement, highly skilled staff could be further trained to successfully to take over the multi-role posts.
- Several people were concerned about out of date procedures or new incomplete procedures for NSTX-U, but they felt the system in place would make sure these procedures were ready before CD-4. One person was concerned about the DCPS. One person was concerned about the CHI system readiness because of loss of experienced personnel. Finally, someone mentioned there are too many acronyms (but improved with webpage update)

- Process to determine what type of training for each procedure not defined in a procedure
- Roles, Responsibilities, Authorities and Accountabilities (R2A2) of COE not defined/represented in operating org chart
- The structure with roles and responsibilities of each position beneath the COE was not presented
- Conduct of Operations Order Matrix not developed

Comments

- Shift supervisor and COE roles could be better defined and made more clear in the documentation
- What role does the physics operator play in machine operation? How do physics operator and COE interact to ensure safe operation of the machine? The roles should be better defined.
- Suggest more training for COGs and COEs in ACC process and SAD and safety envelope
- It would serve the lab better, against the various reasons for loss of staff, if there was one person (and a deputy) per key role. While there is currently no evidence of the multiple roles carried by any one person leading to any conflict of interest (such as science program expediency versus the priority of definite safe working), we do not feel that this is a good policy.
- Above findings indicate R2A2s not well documented for operations organization
- Other attributes of the Conduct of Operation Order may not be documented or clearly implemented.
- Continued attention should be paid to succession planning since many of the staff are approaching retirement age. This is especially important in light of the fact that some of the staff performs multiple roles.

ANSWER TO CHARGE 4 and 5

Charge 4: Does the PPPL Activity Certification Committee (ACC) process ensure that configuration changes are adequately reviewed and appropriately documented in the NSTX-U Safety Assessment Document (SAD) and Safety Certificate?

Charge 5: Does the PPPL Activity Certification Committee (ACC) process, including approval to proceed by the PPPL ES&H Executive Board Chairperson, ensure that PPPL is indeed ready to begin NSTX-U operations?

- Yes, subject to items requiring resolution.

Committee members for Charges 4 and 5

- Kevin Freudenberg (ORNL), Dragoslav Ciric (CCFE), and Tim Scoville (GA)

Method of review:

- Document review and interviews.

Findings

- The existing ACC review process is functioning as an internal readiness review, but in places there is no evidence of external input, to the extent that some serious issues have been missed.
- The experience of the ACC members, and their "hands-on" approach to checking the plant has been and continues to be of immense value for the human safety and plant protection of the facility.
- The guideline for determination of the scope of the ACC review is based primarily on the OP-NSTX-02. However, the ACC review has full authority to expand its scope into any area it sees fit.
- The NSTX-U safety certificate is issued by the ES&H Executive Board based on the recommendation of the ACC review. The safety certificate is required for NSTX-U operation.

- Maintenance activities are not directly input into NSTX-02 or the ACC review process.

- Spot checks of the commissioning procedures and the FMEA, reveal some shortcomings most easily explained as arising from the familiarity of practically every key post-holder with the old plant and its hazards.

    - The typical problems are, in the commissioning procedures, inadequate descriptions of how exactly to perform certain tasks (such as "check the type of gas in the [SF6 towers]", and inadequate requirements for recording findings or branch conditions if certain conditions were not met (e.g. vacuum pressure achieved).

- For the FMEA the old plant and the new differ more than the NSTX-U FMEA recognized (although it is unclear to what extent ACC had approved this document at the time of this Review). One example is that the turbo-pumps will see higher stray magnetic field from the tokamak poloidal fields, which will create higher eddy current heating in the rotor blades, exacerbating their creep behavior and raising the likelihood of explosive disassembly – a serious failure mode of TMPs guarded against by modern suppliers and by many other MFE installations but not mentioned as a hazard in the FMEA.

Comments

- The ACC review was stated to be on time and within schedule but this was not shown explicitly. There is concern that many systems, most notably the DCPS, need to be fully approved and ACC assessment is only half done on that system.
- Responsible line manager decides (engineering judgment) when modifications are big enough to make change to SAD.
- The schedule for bringing NSTX-U up was not discussed in any detail. The ACC stated that their involvement was "just in time" and driven by the new systems coming up that needed review.
- The ACC effectiveness relies heavily on their considerable years of experience to guide activities. However, as senior staff retires, an improved process become more important.
- Since ACC members are themselves part of the long-term cognoscenti of the facility, it is not clear that their further efforts alone will identify the new hazards raised by the change from NSTX to NSTX-U or the unstated things in the commissioning procedures that are not obvious to trainees and other new-comers.

- It would be beneficial to create and maintain a preventative maintenance database.

Items Requiring Resolution Before ISTP

- The NSTX-U Operations group should provide a well-defined startup schedule for use by the ACC and other groups. Hold points should be used to trigger the involvement of the ACC in approvals.

- Consider how to identify the unstated reliance upon prior knowledge in the commissioning procedures. Improvements should be made such as recording values observed (useful for maintenance guidance and confirmation of tasks actually completed).

- Preventative maintenance (PM) activities should be input into NSTX-02 or the ACC review process when applicable, since PM activities may impact assumptions in safety analysis. Explicit decisions should be required by Cog and approved by RLM on whether completeness of maintenance activities is appropriate for startup.

- Arrange for external peer review of the FMEA and evaluate whether any new issues identified must be resolved prior to ISTP.

- **Issues Requiring Resolution After ISTP** Any changes to the NSTX-02 that impacts a control identified in the Safety Certificate or an assumption in the SAD document must automatically trigger an ACC review. This should be included in the PPPL tracking/change system to remove the ambiguity of when an ACC review is required.
- A skill profile for future ACC members is needed.
- At a suitable interval, reassess the ease of use of the procedures by new trainees.

ANSWER TO CHARGE 6

Charge 6: At the time of project completion, will the NSTX Upgrade Project have delivered the Project Objectives as defined in Section 2.2 of the NSTX-U Project Execution Plan?

Yes. It is the opinion of this committee that the demonstration of the two items listed above (Section 2.2.2.2 in the NSTX Project Execution Plan (PEP)), coupled with the successful completion of the required action items, and the completion of the integrated testing OP-NSTX-U will demonstrate that NSTX has been upgraded to permit operation at the desired technical baseline parameters. This will meet the project objective, as defined in Section 2.2.1 of the PEP.

Method of review:

- Document review and presentations during the Readiness Review.

Findings

- The Technical Baseline Parameters for the NSTX Upgrade Project are the following: TF = 1.0 Tesla, Pulse length = 5 seconds, Plasma current = 2 MA, and NB Power = 10-14 MW
- The Center Stack Upgrade and the additional of the second Neutral Beamline will provide the device capabilities to meet the baseline parameters.
- All systems have been designed to meet the baseline parameters. Design reviews have been held for all key systems and have been reviewed by internal project personnel as well as external reviews through the final design review stage. All action items (Chits) identified during the reviews were listed and tracked in a master action item file.
- A procedure exists and is being executed to verify that all action items are resolved, that appropriate personnel have reviewed the resolutions, and that the resolutions are completed prior to the start of integrated testing OP-NSTX-02.
- The execution of the design was reviewed periodically during the project by external review committees and all recommendations of those committees were followed.
- Formal project completion requires demonstration of (1) an ohmic plasma with Ip > 50 kA at a toroidal field greater than 1 kG and (2) installation of the second neutral beamline, including all support services and control systems, and injection of a 40 keV neutral beam into vessel armor for 0.050 seconds.

Comments

- Actual achievement of the baseline parameters over the course of the next few years will require continued testing, including validation of design simulations against measurements.