DESIGN REVIEW DOCUMENTATION – RESULTS

Title: Polar Region – Flanges/O-Rings/Insulators/Supports PDR ___WP#: 2320 _____ (ENG-032)
CAT: ☒A1 ☐A2 ☐A3

Type of Review: ☐ **Peer** ☐ **CDR** ☒ **PDR** ☐ **FDR**

Cognizant Individual: Mark Smith_____ Date of Review: 2 August 2018

Review Board Members:	**Invited Attendees:**	**Other Attendees:**
Chairperson R. Ellis	_____	_____
RE D. Loesser	_____	_____
TA	_____	_____
TA (____)_____	_____	_____
QA J. Graham	_____	_____
ESH J. Levine	_____	_____
	_____	_____
	_____	_____

Regulatory Compliance _____

Please see the attached report for the full list of attendees.

Items Reviewed:	**Sat.**	**Unsat.**	**Comments or n/a if not applicable**
Appropriate requirements identified	☒	☐	_____
Development plans and schedules	☒	☐	_____
Reg. compliance incl. USI/USID and NEPA	☒	☐	_____
Disposition of CHITS from previous reviews	☒	☐	In progress; final resolution before FDR
Cost objectives	☒	☐	_____
Other review objectives addressed	☒	☐	questions from charge letter

SUMMARY OF RESULT: *Please see the attached report.*

Disposition: [check one]
_____ **Acceptable**
xxxxxxx **Acceptable pending resolution of concerns**- CHITS identified above must be resolved prior to installation.
_____ **Incomplete -** Additional design work is required prior to another design review.
_____ **Unsuccessful** – Corrective actions must be taken and another review process must be initiated.

Design Review Chair Person Robert Ellis Digitally signed by Robert Ellis Date: 2018.08.21 14:07:20 -04'00' Date: _____

Cognizant Individual Acceptance Mark Smith Digitally signed by Mark Smith Date: 2018.08.21 15:16:31 -04'00' Date: _____

Distribution: Review Board Members, Operations Center, Responsible Engineer, Cognizant Individuals, Project Manager, Project Director, relevant Technical Authorities, Chief Engineer, Fire Protection Engineer, Attendees, QA, ES&H, Security, Requesting & Performing Dept. Head

Revised 2/19/2018

NSTX-U Recovery Polar Region – Flanges/O-rings/Insulators/Supports - Preliminary Design Review

2 August 2018

Attendees:

R. Ellis*, chair and RE for Diagnostics
I. Zatz*, Recovery Project Engineer
S. Raftopoulos*, Construction Manager and substitute for M. Kalish, RE for Magnets
S. Gerhardt*, Head of Systemm Integration and Research zoperations
T. Stevenson*, Head of Operations and USI Screener
C. Neumeyer*, Chief Engineer
D. Cai*, RE for Vacuum Systems
M. Viola*, Mechanical TA
P. Dugan*, Systems Engineering
M. Sibilia*, Subject Matter Expert (SME)
W. Blanchard*, SME
J. Levine*, ES&H
J. Graham*, QA
V. Riccardo
M. Smith, Cognizant Engineer Polar Region
M. Cropper
D. Loesser, Responsible Engineer Vacuum Vessel and Internal Hardware
P. Titus
M. Safabakhsh
D. Bishop
T. Ronge
S. Horst
J. Burhoe
T. Willard
F. Cai
I. Kunsch
J. Menard
J. Hennessy
S. Gifford
S. Weidner, Princeton University
A. Brooks
R. Hawryluk
H. Zhang
E. Lawrence

D. Cai
J. King, Department of Energy (remote login)
W. Wang (remote login)
Y. Zhai (SME) (remote login)

*Member of Design Review Committee

Introduction

The Extent of Condition (EoC) review of the NSTX-U Recovery Project issued recommendations that led to the redesign of several Polar Region components, including the PF1A/B/C coil supports, centerstack (CS) case and casing support, CS bellows, bellows and divertor flanges, ceramic breaks, and o-ring vacuum seals. The main activities requiring action were:

- Redesign of the PF1A/B/C coil supports allowing for mandrel free coils,
- Implementation of coil preload for PF1A and PF1B coils,
- Alignment of the machine core components and assemblies per NSTX-U-RQMT-RD-011-00,
- Implementation of double O-ring seals with a pumped interspace,
- Addressing over 70 chits from previous reviews.

A Conceptual Design Review for the Polar Region was held on 1-3 August 2017. Inner PF coil supports had a Preliminary Design Review on 27 March 2018.

This PDR presented the designs of the Polar Region components, and the integration of these structures into NSTX-U.

Summary

Introduction

Introduction

Mark Smith presented an overview of the work on the Polar Region design: The charge letter, project organization and team, the scope of this review, introduction to the remaining talks, and a review of the agenda.

The scope of the review was: PF1A/B/C supports and connections, PF1A/B common flange and connections, polar region vacuum seals, bellows and bellows flanges, CS case collar and connections, CS case divertor flange and weld reinforcement, ceramic break, lateral supports, welds and hardware within the polar region, outer skirt, and the polar region assembly.

Requirements

Requirements Presentation

Stefan Gerhardt presented the requirements for the polar region design, showing how they flow from the NSTX-U General Requirements Document (GRD) to the Systems Requirement Document (SRD) and Requirements Documents (RDs). The relevant documents are in the Google drive folder associated with this review, and noted in the presentation. The derivation of electromagnetic forces, starting with the Design Point Spreadsheet, developing 96 operating scenarios, and then force influence matrices, was explained.

Design Overview

Polar Region Design Overview

Mark Smith gave an overview of the design. Starting with an overview of the polar region, he explained how the requirements and interfaces, as well as chits from previous reviews, flowed into the design. The importance of the new alignment and dimensional control requirements (NSTX-U-RQMT-011-00), and design features and fabrication techniques needed to meet them, was noted. Brief descriptions of the inner PF preload mechanism and coil supports, and an analysis of clearances, were presented.

Interface Loads

Interface Loads Presentation

Peter Titus presented the "Interface Loads," consisting of coil loads from operation and disruptions, halo current forces and bake-out heating of the bellows, and normal operating loads on the casing including vertical disruption (VDE) loads, halo current loads, and loads reaction loads from the heat transfer plate due to disruptions. These loads, as well as loads due to coil error fields, were presented, and the documents forming their basis were referenced. The most significant loads were selected and passed to the design and analysis team.

Load Scan

Load Scan Presentation

Art Brooks presented the results of a load scan on the PF1A/B/C coils based on a 2D ANSYS model that was used to calculate a coupling vector of forces from the P4 VDE plasma and eddy currents on each PF coil. The forces were evaluated at three time points: stationary plasma (same forces as the Design Point Spreadsheet), end of drift, and end of quench. VDE forces were added to the coil only forces from each of the 96 operating scenarios. The modeling shows some that the initial modeling assumption of a circular plasma is conservative. Art noted that the disruption requirements have been updated, and the new requirements should be used for work towards the Final Design Review (FDR).

2-Dimensional Global Thermal Model

2-D Thermal Model Presentation

Han Zhang presented the results of a 2-D global thermal model. Five representative operating conditions were analyzed, and plots of operating temperature at the end of a run day were shown. These temperatures were mapped to the more detailed structural models used to evaluate stresses in polar region components.

The 2-D model does not yet have information for water cooling of the o-ring area, and the effect of the bus bar jumper on DC current in the CS casing for bakeout needs to be included.

O-rings and Halo Current Side Force Restraints

O-ring Presentation *Center Stack Side Force Presentation*

Feng Cai presented the design of these two components. A double o-ring, with a pumped interspace, is needed to meet the permeation requirement, and also provides redundancy if an o-ring should leak. The dimensions and tolerances of the seal area were carefully thought out.

Restraints to halo current side forces on the center stack casing are required at the top. These supports act in compression only, with a nominal gap between the restraints and the CS casing required to accommodate growth during bakeout. A simple and effective design, using shims similar to past designs, was presented.

Ceramic Break Flange Assembly Analysis

Ceramic Break Flange Analysis Presentation

Thomas Ronge presented an analysis of the ceramic break flange analysis, including a description of the PF1C flange connection. A special nut with insulating washers and o-ring seals minimizes the risk of water entering the area of the ceramic break. With 7500 pounds preload on each flange bolt, complete contact is maintained when halo current forces are applied. Stesses in the insulating washers and the spacer are acceptable.

Bellows Analysis

Bellows Analysis Presentation

Thomas Ronge presented an analysis of the CS bellows. The model includes portions of the upper and lower flange, and the flange models are partitioned to allow for mesh refinement. Splits at bellows/flange intersections allow for weld resultant forces to be computed by means of line connections. Displacements due to installation, and those externally imposed, were included in the analysis. The existing bellows design passes the 20x life (20 *20000 = 400000 cycles) fatigue criterion, but fails the 2x stress criterion. This may be improved through more detailed analyses and higher fidelity fatigue assessments, or a new bellows design.

Polar Region Analysis

Polar Region Analysis Presentation

Doug Bishop presented an analysis of the polar region. This uses stand-alone models of PF1A, PF1B and PF1C, and models of the upper and lower polar regions. The models of the polar regions include segments of coil buswork in order to establish proper boundary conditions at the coil leads. The coil models use "smeared" orthotropic material properties. Each polar region assembly has approximately 10 million elements. A mesh convergence study will be needed for the final design review.

The stresses in the coil slings, flanges and attachment hardware were acceptable. The skirt weldment has a factor of safety less than one, and will require some design changes to reduce these stresses. Several options were identified in the talk. Reducing the stresses is seen as a straightforward exercise.

Assembly and Tolerances

Assembly and Tolerances Presentation

Ian Kunsch presented the assembly plan and tolerances. Starting from shift and tilt goals from the dimensional control requirements, he showed the results of cumulative tolerances evaluated two ways: using worst case addition and a Monte Carlo technique. The Monte Carlo technique shows that dimensional goals will be met using the expected fabrication and assembly tolerances; using the worst-case addition, PF1B may exceed its allowable tilt.

The merits of in-house manufacture versus procurement from outside suppliers were assessed for major components. The centerstack case rework will certainly be done outside; evaluation of other components will continue.

Prototypes of some components, including Inconel 718 weld specimens, coil slings, cold worked Inconel 625 components, and a ceramic break mock-up, are planned.

Center Stack Case

CSC Presentation

Mark Smith presented work to be done on the centerstack case, much of which is technically outside of the scope of this review. Centerstack case tasks pertaining to the polar region are: reinforce the Inboard Divertor vertical (IBDV) to CSC flange joint, enlarge the CSC collar recess inside diameter, machine the CSC flange for the CSC collar pins and bolts, remove and replace the bellows and bellows flange, install the CSC collar onto the CSC, post machine the CSC collar for flatness and machine bolt holes. Machining operations should occur after all welding is complete, and metrology will be required in order to ensure high precision.

Center Stack Case Weld Stress

CSCWS Presentation

Peter Titus presented the analysis of the CSC weld. As above, this is mostly outside the scope of this review. The original NSTX-U design had a small intermittent weld between the casing and the PF1B mandrel. This weld survived the bakeout but was overstressed. Analyses of proposed new designs were shown.

Safety Analysis Document (SAD) and Accelerator Safety Envelope (ASE) Considerations

SAD & ASE Presentation

Stefan Gerhardt discussed the impact of this work on safety analysis in SAD R6. The elimination of the lower ceramic break is noteworthy in that it mitigates a lithium hazard observed in the DVVRs. The SAD should be updated to reflect this, and also to explain why lithium cannot access the upper ceramic break.

Cost and Schedule, Risk

Cost and Schedule Presentation

Mark Smith presented the most recent cost, schedule, and risk summary. The total estimated polar region cost is ~$12M. This is an increase of ~$9M. Reasons for the increased cost are an improved basis of the estimate, improved design assurance and reliability, and improved physics performance through better alignment. The schedule estimate is also more detailed. A final design review is planned for November 2018. Fabrication of PF1A and PF1B supports is planned for ~8 months after CDE2/3a approval. Completion of the upper and lower PF1A/B assemblies is planned for ~3 months after the coil supports are completed. PF1C support subassemblies is planned for ~6 months after CDE2/3a approval.

The polar region has 22 total risks. Eight are related to design, one to procurement, six to fabrication, four to assembly, and three to the overall project.

Old Chits

Prior Chit Summary

A summary of existing chits, going back to DVVRs, was presented by Mark Smith. There are a total of 75, of which 39 are addressed in the design presented at this review. Eighteen others are in progress. All chits, including those from this review, will be closed prior to the final design review.

Chits from this review

Chit Responses

Thirty-five chits were generated at this review. None was serious enough to cast doubt on the quality of this design. These chits, as mentioned above, will be closed prior to the final design review.

Conclusions of the Review Board

The polar region design and analysis team did an outstanding job in advancing the design to this level. We should proceed to a final design review based on the work presented here. The review is “successful, pending resolution of concerns.”

National Spherical Torus eXperiment Upgrade

VVIH-180725-IJZ-01

TO: M. SMITH
FROM: I. ZATZ
SUBJECT: CHARGE FOR POLAR REGION PRELIMINARY DESIGN REVIEW (PDR) [PDR# 2320-PDR-016]

1 Introduction

During the Extent of Condition (EoC) review, several Design Verification & Validation Review (DVVR) issues and EoC recommendations called for various changes to NSTX-U including an update of the requirements documents leading to redesign of several Polar Region components. The redesign efforts in the Polar region were extensive and include, but are not limited to: PF1A/B/C coil supports, CS case and the casing support, CS bellows, the bellows and divertor flanges, ceramic breaks, and o-ring vacuum seals.

Main issues requiring action in the Polar Region were:

- Redesign of the PF1A/B/C coil supports allowing for mandrel free coils.
- Implementation of coil preload for PF1A and B coils.
- Alignment of the machine core components and assemblies per NSTX-U-RQMT-RD-011-00.
- Implementation of double O-ring seals with a pumped interspace.
- Addressing over 70 chits from the various prior reviews.

Conceptual designs for the Polar Region systems, structures and components (SSC) were developed and presented at a Conceptual Design Review (CDR) on August 1-3, 2017. Additionally, designs for mandrel-less Inner PF Coil supports were further developed and presented at the NSTX-U Recovery Project Preliminary Design Review (PDR) held on March 27, 2017.

This PDR presents the designs of the Polar Region SSC as they have evolved along with the integration of these structures into the overall NSTX-U machine.

Design review methodology will conform to the latest version of ENG-033 (Rev. 6) based on A1 risk classification.

2 Purpose

The purpose of the PDR is to review the development of the NSTX-U Polar region SSC that has taken place since the designs presented at the aforementioned CDR on 8/1/2017

and the PDR on 3/27/2018.

3 Requirements

NSTX-U-RQMT-GRD-001
NSTX-U-RQMT-SRD-002-00: Magnets
NSTX-U-RQMT-SRD-004: VVIH
NSTX_CS_Upgrade_Open_Revision_03_20_18
NSTX-CRIT-0001-02: Structural Design Criteria
NSTX-U-RQMT-RD-003-00: Disruptions
NSTX-U-RQMT-RD-005-00: CS Air Side Diagnostics
NSTX-U-RQMT-RD-008-00: Machine Instrumentation
NSTX-U-RQMT-RD-010-00: Magnetic Materials
NSTX-U-RQMT-RD-011-00: Alignment / Dimensional Control
NSTX-U-RQMT-RD-012-00: Inner PFs
NSTX-U-RQMT-RD-013-00: Thermal Scenarios

4 Scope

The scope of this PDR includes the upper and lower Polar Region systems, structures, and components. Instrumentation is out of scope.

5 Methodology

The PDR shall be conducted in accordance with existing PPPL procedure ENG-033 “Design Verification”, supplemented by the participation of the NSTX-U Project Engineer (PE).

The following are the PDR objectives (as applicable):

- Verify that all requirements are being addressed; Identify requirements or design conflicts and potential "show-stoppers"
- Assure the appropriate incorporation of recommendations from previous reviews
- Review the results of analyses, calculations, and tests conducted to obtain additional information for the design
- Review the ability to implement the proposed design taking into consideration capabilities, tolerances, costs, quality, reliability, human performance and ergonomics, security, and ES&H security
- Review updated design
- Review manufacturability
- Review development plans and schedules
- Review procurement issues, e.g. build vs. buy
- Review test requirements and plans
- Review SAD/ASE considerations

PDR deliverables shall include the following (as applicable):

- Revised requirements
- Resolution of high priority chits
- Minutes and chit progress from underlying peer reviews
- Design and development information
- Calculations
- Procurement strategy
- Cost & Schedule considerations
- SAD/ASE considerations
- Minutes and chit assignments

Review materials shall be presented to the DRC and PE for acceptance, and then distributed to the review committee one week in advance of the review.

5 Review Committee

The Design Review Committee shall be constituted as follows. In case any persons are absent, the review may proceed at the discretion of the DRC and PE.

R Ellis	Chairperson + ME TA + RE Diagnostics
I. Zatz	Recovery Project Engineer
S. Raftopoulos	Construction Manager
S. Gerhardt	Head System Integration + Research Operations
M. Kalish	RE Magnets
T. Stevenson	Head Operations + USI Screener
C. Neumyer	Chief Engineer
D. Cai	RE Vacuum Systems
M. Viola	Mechanical TA
P. Dugan	System Engineering
M. Sibilia	SME
Y. Zhai	SME
W. Blanchard	SME
ES&H Representative	SAD/ASE considerations
QA Representative	QA

6 Agenda

The review shall be accomplished over 1 day, tentatively scheduled for August 2, 2018, with the following preliminary agenda:

Start	Duration	Topic	Presenter
9:00 AM	10 m	Introduction	Smith
9:10 AM	15 + 5 m	Requirements	Gerhardt
9:30 AM	40 + 10 m	Polar Region Design	Smith
10:20 AM	10 m	Break	
10:30 AM	60 + 10 m	Integrated & Supporting Analysis	Titus, Han, Brooks
11:40 AM	15 + 5 m	O-ring Seals	Cai
12:00 PM	15 + 5 m	Lateral Supports	Cai
12:20 PM	30 m	lunch	
12:50 PM	15 + 5 m	Ceramic Break	Ronge
1:10 PM	15 + 5 m	Bellows Analysis	Ronge
1:30 PM	30 + 20 m	Polar Region Analysis	Bishop
2:20 PM	10 m	Break	
2:30 PM	15 + 5 m	Assembly Plan & Tolerances	Kunsch
2:50 PM	15 + 5 m	Fabrication & Manufacturing	Kunsch
3:10 PM	15 + 5 m	Prototypes	Kunsch
3:30 PM	15 + 5 m	CS Case Modifications	Smith
3:50 PM	10 m	Break	
4:00 PM	20 + 10 m	CS Case Analysis	Titus
4:30 PM	15 + 5 m	SAD	Gerhardt
4:50 PM	15 + 5 m	Cost, Schedule, Risk	Smith
5:10 PM	15 + 5 m	Prior Chits	Smith
5:30 PM	30 m	CHITs Review by Committee	

cc:

T. Egebo
R. Ellis
R. Feder
S. Gerhardt
J. Hennessy
P. Johnson – DOE PSO
M. Kalish
J. King – DOE
S. Langish
J. Levine – ES&H
J. Menard
M. Viola
T. Ronge
D. Bishop
I. Zatz
P. Dugan
M. Sibilia
D. Loesser
Y. Zhai
I. Kunsch
F. Cai
T. Willard
A. Brooks
J. Mitchell
S. Gifford
J. Winston
C. Neumeyer
W. Blanchard
D. Cai
S. Raftopoulos
V. Riccardo
T. Stevenson
P. Titus
H. Zhang
S. Weidner - PU

PPPL QA

NSTX-U File