To: PPPL distribution

From: Thomas Painter, Invited Reviewer

Date: September 24, 2013

Subject: Findings of Two Day PPPL Site Visit on September 17 – 18, 2013.

Charge to reviewer:

"The motivation for contacting you is to have other magnet experts with experience in fabricating large, one-of-a kind research magnets such as this take an independent look at our design, manufacturing approaches, and operations details to jointly consider ways to improve our schedule performance going forward so that the new Centerstack assembly can be completed and ready for installation by May 2014 or sooner."

Findings:

I would first like to thank you for your kind hospitality. Based on the documentation reviewed, discussions and meetings held during my two day site visit, it appears that the NSTX-U project is well-positioned to complete the Centerstack assembly by May, 2014. Further, the coil fabrication designs and processes are consistent with my experience in winding and epoxy impregnating large coils. There have been recent schedule setbacks primarily attributable to a failed supplier of a key component, the epoxy impregnation mold. However, all the risky, large, high-tolerance components are now in-house which reduces substantially the schedule uncertainty moving forward. Further, corrective actions have been implemented to prevent future supplier failures as described below. It appears as if PPPL is using the latest best business, technical and quality practices, and that the team is eager and capable of finishing the project within the present schedule predictions.

A few of the laboratory practices that I found to be very good to excellent are as follows.

- Writing and implementation of detailed fabrication procedures documenting key inspections and safety issues.
- Communications processes that integrate the NSTX-U with safety and matrix managers including daily "kickoff" meetings.
- NSTX-U team coordination and morale.
- Schedule predictions and monitoring.

It is inevitable in first-of-a-kind large fabrication projects that there will be adverse surprises from which the team must learn and adjust to prevent a repeat of similar events.

For the NSTX-U project, a supplier of a key element, namely the VPI mold for the quadrants for the Centerstack has failed to perform. The supplier failure has continued to affect the project schedule over the last six months due to the time required for subsequent in-house fabrication of the quadrant mold lid. However, the supplier failure was identified, a root-cause failure analysis performed and corrective actions taken as follows.

- A higher level of supplier QA surveillance has been implemented including more frequent teleconferences, sometimes on a weekly basis, more frequent supplier visits as required, and an expanded supplier QA survey to identify specific and detailed welding, fabrication and testing capabilities. The expanded QA survey should be extremely helpful in identifying and selecting the best suited suppliers for future procurements.

- A dedicated receiving QC engineer position has been added and filled to ensure timely QC inspections of procured hardware.
- A detailed quality records program has been implemented to allow easy access of critical supplier data and records of past supplier performance.

Looking forward, my opinion is that the 7 month time allotted for winding of the OH coil and completion of the center stack is sufficient based on the following:

- Sufficient staffing of technicians. Presently 10 technicians are assigned to the project, which will enable two winding shifts including Saturdays as required after the first of four layers are completed. An area of concern is that the technicians may prematurely be assigned to other projects. In my opinion, it is important that the project maintain the full contingent of ten technicians in order to ensure the winding schedule is maintained or expedited.
- Sufficient staffing of engineers. The two engineers assigned (one full time and one half time) to oversee and direct the Centerstack fabrication seems to be sufficient, but again it is important that these engineers not be reprioritized with other tasks during this time so that they can focus on completion of the Centerstack.
- The demonstrated ability to complete the prior OH coil in six months. The time required to complete the prior OH coil provides a baseline precedence for this activity. There are however some key differences. The first being that the present OH coil is more complicated and the second being that the present OH is being wound in-house instead of at a supplier's facility. These differences are mitigated somewhat because the responsible engineer was involved intimately in the surveillance at the supplier's facility during fabrication of the prior OH coil. The second being that there are similar key processes and duplicate facilities carried over from the prior OH coil fabrication such as the brazing processes and reproduction of modified supplier winding tooling to build the in-house winding line.
- There are no further large high-tolerance assemblies to be produced. The VPI molds and the outer casing were the largest and most difficult to build within the tight tolerances required and all are now in-house and verified to be within acceptable tolerances.

However, there are some areas of concern on which I would focus attention moving forward as follows.

- Completion of the layer to layer brazing and match-fitting of the joggle bends and fillers. Coil leads and layer-to-layer interfaces are high-risk areas that are typically the first to fail in operation of large coil assemblies. For the OH coil, there will be custom joggle bends and match-fit G10 hardware that must be fabricated all of which are subject nominally to 4x the Lorentz loading as the prior system due to the doubling of magnetic field. It is important to allow as much time as required to complete these critical areas despite any resultant schedule delays. It is especially important that tolerances be identified and QC inspections implemented to assure the lead and layer transitions are built according to the engineering requirements and tolerances. Under-performing or low-quality lead and layer transitions may result in premature operational failure.

Requested Information:

During the course of my visit, many technical issues were discussed relevant to large coil fabrication. I would like to provide the following requested information from our discussions.

- A Frequency Spectrum Analyzer for detection of short circuits as a coil is being wound.
- Information on Bleeder Lease, a permeable release tape for epoxy impregnation processes.
- Information on non-magnetic weld filler rod.

- Some storyboard examples typically used to develop and finalize fabrication processes on high-field magnets and systems.
- Some example VPI procedures used at the NHMFL.

Frequency Spectrum Analyzer. As mentioned in our meetings, the NHMFL has implemented a frequency spectrum analyzer, Hioki model 3 522-50, as the preferred method for detecting shorts in a coil as it is being wound. I have included a presentation file made by Dr. Hartmut Ehmler from Helmholtz-Centrum Berlin on the subject of insulation testing that describes the various methods he has considered and compared in file “121201 Ehmler short_circuit_presentation”. I have also included the latest work instruction we have used to perform the impedence spectrum measurement in file “130923 Painter NHMFL server download of QWI-013-R1 Measure impedance spectrum”.

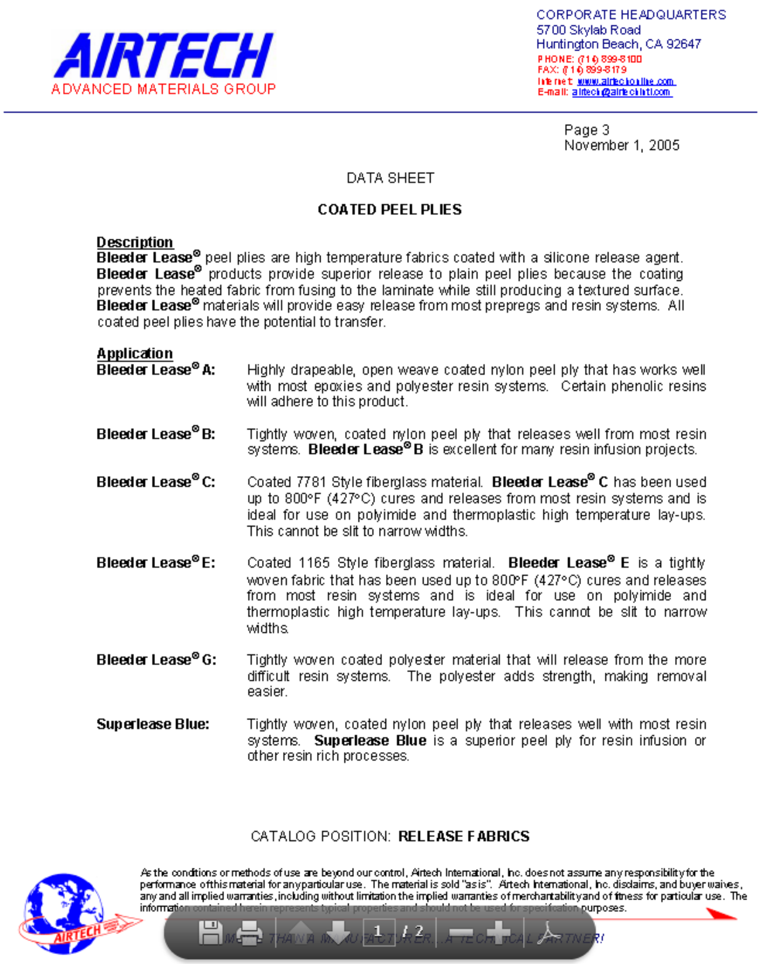
Bleeder Lease. Bleeder Lease is a coated tape used in epoxy impregnations that is permeable to epoxy but does not bond to epoxy. It is used to wrap an item being impregnated to allow good flow of epoxy to all surfaces of the item. After the epoxy is cured, the bleeder lease forms a good break plane for removal of excess epoxy from around the item impregnated. The NHMFL Magnet Science and Technology group uses Bleeder Lease B for impregnations of their large coils. Note that the Bleeder Lease cannot be used for filled epoxies such as stycast because it acts as a filter to the filling agents. See Figure 1 for a data sheet and a photo of a typical roll of Bleeder Lease B.

Non-magnetic Filler Rod. The MS&T uses Weld Filler Rod ER316MnNF to produce a non-magnetic weld. This rod also had a European designation as Grinox T-51 filler rod. I have attached a file “0003 Swenson Publication on low mu steel” of a publication written by Chuck Swenson and Denis Markiewicz on the subject for reference.

Storyboards. In my experience, storyboards are an efficient and effective way to focus discussions, development and implementation of fabrication processes. I have attached a file “130828 Deneute Storyboard to Flip Conductor and Install Shipping Container Base” containing a detailed storyboard from High Performance Magnetics to describe a critical lift procedure for flipping our 4 m diameter, 16,000 lb spool of conductor from axis horizontal to axis vertical. Not all storyboards must be this long or detailed. Even a few slides describing the processes are often very helpful for more effectively communicating ideas and processes.

Other VPI Procedure Examples. It may be of interest to review other large coil epoxy impregnation processes. For reference, I have attached the following VPI procedures that use a potting tank instead of a mold.

- File “001016 Painter P4 VPI procedures (from 900 MHz coil fabrication)”, which contains the procedures from October, 2000 used to vacuum-pressure impregnate the 900 MHz superconducting Nb3Sn coils at the NHMFL with a developed cryogenically-tough epoxy.
- File “130924 Marshall QWI-028-PC1-IR-Dec-5-2012 Prep coil for impreg”, which contains preparation procedures for our latest impregnation on a CICC coil.
- File “130924 Marshall QWI-029-Rev 2 - Epoxy Impreg”, which contains the impregnation procedures for our latest impregnation on a CICC coil.



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DATA SHEET

COATED PEEL PLIES

Description
Bleeder Lease® peel plies are high temperature fabrics coated with a silicone release agent. **Bleeder Lease®** products provide superior release to plain peel plies because the coating prevents the heated fabric from fusing to the laminate while still producing a textured surface. **Bleeder Lease®** materials will provide easy release from most prepregs and resin systems. All coated peel plies have the potential to transfer.

Application

Bleeder Lease® A:	Highly drapeable, open weave coated nylon peel ply that has works well with most epoxies and polyester resin systems. Certain phenolic resins will adhere to this product.
Bleeder Lease® B:	Tightly woven, coated nylon peel ply that releases well from most resin systems. **Bleeder Lease® B** is excellent for many resin infusion projects.
Bleeder Lease® C:	Coated 7781 Style fiberglass material. **Bleeder Lease® C** has been used up to 800°F (427°C) cures and releases from most resin systems and is ideal for use on polyimide and thermoplastic high temperature lay-ups. This cannot be slit to narrow widths.
Bleeder Lease® E:	Coated 1165 Style fiberglass material. **Bleeder Lease® E** is a tightly woven fabric that has been used up to 800°F (427°C) cures and releases from most resin systems and is ideal for use on polyimide and thermoplastic high temperature lay-ups. This cannot be slit to narrow widths.
Bleeder Lease® G:	Tightly woven coated polyester material that will release from the more difficult resin systems. The polyester adds strength, making removal easier.
Superlease Blue:	Tightly woven, coated nylon peel ply that releases well with most resin systems. **Superlease Blue** is a superior peel ply for resin infusion or other resin rich processes.

CATALOG POSITION: **RELEASE FABRICS**

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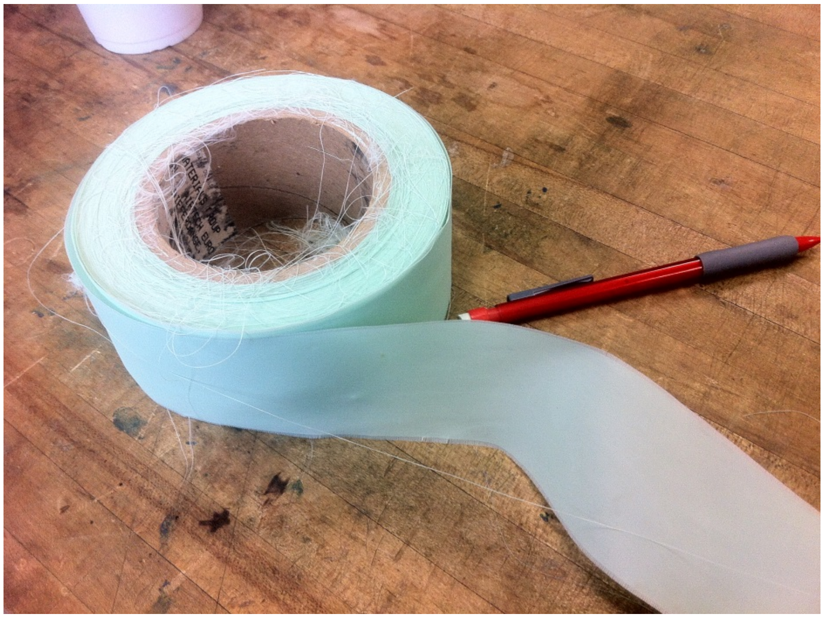

Fig. 1 – Data Sheet on Bleeder Lease above and photograph of a roll of Bleeder Lease B below.