**US High Field Test Facility Project**

**Large Dipole Design, Fabrication and Test**

**WBS DICTIONARY**

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| **Prepared by:** |
| **Reviewed by:** |
| **Approved by:** |

**Revision History**

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| **Revision** | **Date** | **Section No.** | **Revision Description** |
| 1 | 1-Oct-2019 | All | Initial Release |
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Description of individual WBS elements

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1 | Large Dipole Project | No |
| **WBS Description** | | |
| **Scope of Work**  Design, Fabrication and Test of a large aperture dipole to be delivered to the US facility for testing cables and inserts at high field.  A high-field test facility has been determined to be of critical value to the development of conductors for the next generation fusion machines, high energy colliders for particle and nuclear physics, and other applications such as high field NMR, MRI, and ECR sources. The large aperture dipole magnet providing background field to the samples is the core component for this facility. Key performance goals that have been developed with input from stakeholders from the community, including University, Laboratory, and industry. Major requirements include high-field (>15 T), large bore (~100x150 mm), and adequate good field region (~75cm). The magnet design is based on R&D and development carried out over the last 15 years and demonstrated in both prototype and facility magnets up to 100 mm bore and 14.6 T field.  References:   * S. Prestemon. J. Minervini et al., “High Temperature Superconductor Cable Test Facility Specifications”, July 16, 2018. * G. Velev, S. Prestemon, G. Sabbi, “Conceptual Cost and Schedule for an HTS Cable Test Facility”, October 22, 2018.   **WBS Deliverables**  **Threshold**: delivery of a fully tested large aperture dipole with uniform dipole field of 15 T over a length of >75 cm, clear bore of 100x150 mm, outer dimensions, weight, and powering characteristics compatible with the high field test facility cryogenic, mechanical and electrical infrastructure.  **Objective**: achieve a dipole field of 16 T. | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.1 | Project Management | Yes |
| **WBS Description** | | |
| **Scope of Work**  Provide labor resources for Project Management, Engineering, Project Controls, Finance, ES&H, Quality, Risk, and Procurement.  Note: further details will be added pending discussion with DOE on project management plans.  **Project Office Composition**  Project Manager, Project Engineer, Project Control staff including Cost/Schedule, ES&H, Quality Assurance and Procurement.  **WBS Deliverables**  Project controls and documentation, reviews, risk assessment, configuration change control, schedule and cost analysis and reporting. | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.2 | Test facility integration and coordination | Yes |
| **WBS Description** | | |
| **Scope of Work**  Define mechanical and electrical interfaces between magnet and test facility to ensure a successful qualification test, followed by final installation and operation in the high field test facility.  **Scope Assumptions/Exclusions**  Key magnet parameters such as outer dimension boundaries, magnet weight, maximum operating current, maximum stored energy have been already defined and are not expected to change  Key interfaces with the sample holder have also been defined in particular the inner profile of the clear bore which will be compatible with both SULTAN (ITER) and FRESCA2 samples.  **WBS Deliverables**  Documentation and approval of electrical and mechanical interfaces between magnet and facility | | |

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| 1.3 | Preliminary Design | Yes |
| **WBS Description** | | |
| **Scope of Work**  Evaluation of design alternatives for wire, cable, coil geometry, and mechanical structure. Fabrication of prototype cables using representative strand, evaluation of their mechanical stability, critical current degradation, and RRR. Selection of the cable and magnet parameters to achieve an optimal balance of performance, cost and schedule. Preliminary magnetic, mechanical and protection analysis to ensure that the key parameters (operating margins, coil stresses, quench voltages/temperatures etc.) are within established limits so that that target performance can be achieved.  **Scope Assumptions/Exclusions**  A block-coil layout is assumed based on experience from the HD, LD and FRESCA2 development, and the recent HEPdipo design effort carried out by a collaboration of CERN, PSI, EFDA and LBNL over the last two years.  **WBS Deliverables**  Conceptual design report | | |

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| 1.4 | Engineering design | Yes |
| **WBS Description** | | |
| **Scope of Work**  Based on the conceptual design, refine all details of the coil and structure, and the magnet assembly plan. Transition from physics models (e.g. TOSCA, ANSYS etc.) to engineering CAD models to be used as a basis for the design and procurement of individual parts and tooling, and to define the magnet assembly process ensuring its viability at each step.  **Scope Assumptions/Exclusions**  Several key design parameters such as coil heat treatment schedule, short sample parameters, pre-load targets etc. will be confirmed at later steps following measurements of the production wire, results from witness samples reacted with the coils, feedback from the structure assembly with dummy coils, etc.    **WBS Deliverables**  CAD models of the coil and structure. Engineering Design Report. | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.5 | Wire specification and procurement | Yes |
| **WBS Description** | | |
| **Scope of Work**  Develop and approve specification of wire design and performance requirements  Place contracts for wire procurement, including tests to be performed by the vendor prior to shipping  Monitor wire production and address any issues that might arise. Evaluate results of vendor’s test, approve shipping, and receive wire.  Perform additional verification and optimization of electromagnetic properties at LBNL, in particular Ic and RRR. Specify coil heat treatment schedule.  **Scope Assumptions/Exclusions**  The possibility to take advantage of existing/ongoing wire procurements in order to accelerate the delivery schedule and/or reduce cost will be evaluated during the conceptual design phase.  **WBS Deliverables**  Availability of fully qualified wire in accordance with the cabling schedule. | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.6 | Cable Fabrication, characterization and insulation | Yes |
| **WBS Description** | | |
| **Scope of Work**  Fabricate cable for two copper coils, two practice coils, four production coils and two spare coils. Depending on wire piece length, multiple cable ULs may be combined in a single run. Task activities include strand mapping based on available inventory, re-spooling and mounting, cabling run and QC.  Quality Control activities include geometry measurements (cable dimensions, twist); Ic and RRR testing of extracted strands; and measurement of post-braiding insulation thickness by the ten-stack method. Copper cable QC is limited to dimensional measurements and twist angle.  Cable insulation is expected to be performed by an external vendor. A fiberglass braid will be installed on the cable following established processed for Nb3Sn cables.  **Scope Assumptions/Exclusions**  Following recent experience, cable production yield is assumed to be 90% (i.e., 1 additional cable run is planned, including conductor and labor)  Three extracted strand samples for each cable UL are to be tested for Ic  Five extracted strand samples for each cable UL are to be tested for RRR  Insulation to be performed by an external vendor  **WBS Deliverables**  Cable for 10 coils (as indicated above) fully qualified and characterized for coil fabrication. | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.7 | Coil Parts, Materials, and Tooling | Yes |
| **WBS Description** | | |
| **Scope of Work**  Design and procurement of parts for the fabrication of 10 coils (five inner double-layers and five outer double-layers). Coil parts include poles, base and top plates, end wedges, side rails, layer transition and splice supports, consumable materials (ground insulation, binder, and epoxy), instrumentation (traces, voltage taps, strain gauges, wiring). This task includes engineering drawings and specifications, placing contracts, monitoring production, analysis of qualification tests prior to shipping, performing additional qualification tests on receiving, and storing prior to coil production.  Design and procurement of winding tooling. This task includes engineering design/drawings and component specifications; placing contracts; monitoring production; analysis of qualification tests prior to shipping; additional qualification tests on delivery, and tooling assembly at LBNL.  Design and procurement of reaction/impregnation tooling. This task includes engineering drawings and specification, placing contracts, monitoring production, analysis of qualification tests prior to shipping, additional qualification tests on delivery, and tooling assembly at LBNL.  **Scope Assumptions/Exclusions**  **WBS Deliverables**   * Parts for the fabrication of 10 coils * Two sets of winding/curing tooling (inner and outer double-layer) * Two sets of reaction tooling (inner and outer double-layer) * Two sets of impregnation tooling (inner and outer double-layer) | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.8 | Coil Fabrication | Yes |
| **WBS Description** | | |
| **Scope of Work**  Fabricate two copper coils, two practice coils, four production coils and two spare coils. Major steps are winding, curing, reaction impregnation and instrumentation.  The copper coils are mainly directed at establishing the winding and impregnation procedures, verifying the operation of the tooling, and making adjustments as needed.  The practice coils will further develop the winding and impregnation procedure, but focus on the reaction process in particular provisions for coil dimensional changes and avoiding any damage to the conductor.  The production and spare coils will focus on product uniformity and detailed QA at all steps.  **Scope Assumptions/Exclusions**  **WBS Deliverables**  For copper and practice coils: detailed report of findings and final procedures (travelers) for fabrication of the production and spare coils  For production and spare coils: Six fully qualified coils for magnet fabrication (three coils for each double-layer) | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.9 | Structure Fabrication and Pre-assembly | Yes |
| **WBS Description** | | |
| **Scope of Work**  Procurement of structure components (shell, yoke, masters, pads, axial support components, keys, strain gauges and wires). This task includes engineering drawings and specifications, placing contracts, monitoring production, analysis of qualification tests prior to shipping, additional qualification tests on delivery. Pre-assembly of laminations to be performed at either the vendor or LBNL.  Install strain gauges on shell; perform shell-yoke sub-assembly  Procure dummy coil pack, insert in structure, pre-load and perform a cool-down test. Analysis of results.  **Scope Assumptions/Exclusions**  The possibility to use existing shell and yoke laminations will be evaluated as part of the conceptual design.  **WBS Deliverables**  Fully qualified structure ready to accept the coil pack for assembly. | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.10 | Magnet assembly and shipping | Yes |
| **WBS Description** | | |
| **Scope of Work**  Receive, check and prepare coils; Assemble collar packs and coil packs; Insert coil packs, setup bladders, and perform azimuthal and axial preload, and conduct electrical QC.  Prepare for shipment and ship the magnet assembly to FNAL for vertical testing.  **Scope Assumptions/Exclusions**  Two full cycles of assembly, and one full disassembly, are included in the work plan. This will allow an adjustment of pre-load or replacing coils with spares, following the results of the first test.  **WBS Deliverables**  Assembled magnet fully qualified for vertical test. | | |

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| **WBS Code** | **WBS Name** | **Control Account** |
| 1.11 | Magnet qualification and final installation | Yes |
| **WBS Description** | | |
| **Scope of Work**  Planning and supervision of the magnet vertical tests to be performed at Fermilab, and analysis of the test results in collaboration with the Fermilab team. Support of the final installation in the high field facility.  **Scope Assumptions/Exclusions**  It is assumed that a test report will be provided by Fermilab, and detailed test data will be shared in a suitable format for further analysis by LBNL.  **WBS Deliverables**  Analysis of magnet test results to be used as a basis for further optimization, and to establish performance boundaries and operational procedures for the high field test facility | | |