Thomas Jefferson National Accelerator Facility

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SPECIFICATION NO:

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12000 Jefferson Avenue

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TITLE: Hall D tagger magnet core and coils Specification	Specification #:
BY: William Crahen Dated:	Approved:
Checked:	Approved:

SUMMARY OF CHANGES FROM PREVIOUS REVISION:

REV	ECO#	DESCRIPTION	BY	CHK.	APP.	APP.	DATE

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1 STATEMENT OF WORK

1.1 Scope

The Thomas Jefferson National Accelerator Facility (Jefferson Lab) requires one normal conducting dipole C-magnet (Tagger Magnet) with integrated vacuum vessel for the Hall-D photon source to be installed within its Continuous Electron Beam Accelerator Facility (CEBAF). A 12 GeV electron beam will pass through a thin crystal radiator, producing a narrow beam composed of a mixture of particles including electrons and photons. This "mixture" will then enter the air gap in the Tagger magnet vacuum chamber. The photons continue to travel in a straight line through the vacuum chamber and onwards to Hall D, while the electrons are curved by the magnetic field into a fan shape (curvature reflecting the electron energy). These electrons will then proceed to a detector array. The locations of the detectors in this array correspond to calculated flight paths for the different energy electrons, which are in turn determined by the strength of the magnetic field. **For this reason, the magnetic field must be very uniform and precisely known in advance, hence the need for precisely know core geometry and metallurgy.** An isometric view of the Hall-D tagger hall showing the Tagger Magnet installed along with the nearby equipment is shown at the end of this document.

- Due to the radiation environment and the interrelationship with other system components, magnet replacement/repair is an expensive and difficult procedure. Strict adherence to these specifications and the associated drawings is essential to minimize the risk of magnet failure for any reason.

- Jefferson Lab will appoint a technical representative authorized to interact with the vendor. The Jefferson Lab Technical Representative (SOTR) for the Tagger Magnet contract will be a Jefferson Lab staff engineer. Jefferson Lab reserves the right to appoint an Alternate Representative to cover occasions when the SOTR is unavailable. Jefferson Lab reserves the right to change the individual designated as Technical Representative. Jefferson Lab reserves the right to send additional support personnel along with the Technical Representative to any function. The Jefferson Lab Technical Representative will review and approve all required documentation, make all Jefferson Lab required inspections, approve all milestones and other submittals and deliverables required by the Tagger Magnet contract.

- Any aspects of the Tagger magnet which are not covered explicitly by this document, but which are obviously necessary to meet the requirements shall be furnished by JLAB. In the event of an oversight and/or apparent error in this

specification, the vendor shall notify the Jefferson Lab Technical Representative to make the needed changes.

1.2 Information Furnished by JLAB prior to contract award

A build-to-print design for the Tagger Magnet system is provided. It is based upon extensive ANSYS analysis as well as successful operation of a similar tagging spectrometer at Jefferson Lab.

Specifications for a DC power system complete with 3 PPM DC source, polarity switch, and current transductor. This system will be made available after contract award for acceptance testing of the magnet. The vendor may choose to provide his own power system. If this is the case, vendor must provide similar documentation to JLAB for approval.

1.3 Items Furnished by JLAB after contract award

The DC power system described above will be delivered to the vendor at no cost.

1.4 Deliverables to JLAB prior to contract award

Manufacturing Plan

The vendor shall submit a manufacturing plan to JLAB. The plan shall include descriptions of work flow and processes, including inspection tests and "hold points" for JLAB approval. **Special tooling/fixtures to be fabricated shall be identified and defined in some detail** (sketches are sufficient). Final detail/drawings to be provided to JLAB after award of contract. The Manufacturing Plan shall include the integration of the vendor's Quality Assurance Program.

- All special tooling/fixtures fabricated for the manufacture of the magnet cores and coil assemblies becomes the property of Jefferson Lab and shall be shipped to Jefferson Lab upon completion of the contract at no additional cost. **This is to include any fixtures fabricated for lifting, shipping and off-loading.**

Any changes to the manufacturing plan submitted with the proposal are not to be incorporated until they have been reviewed and approval has been granted by the Jefferson Lab Subcontracting Officer (SO) and the Subcontracting Officer's Technical Representative (SOTR).

Quality Assurance Plan

The vendor shall submit as part of the proposal a quality assurance plan for JLAB approval to the JLAB technical representative (SOTR). This plan shall provide for the tracking of each part/component as it moves through the manufacturing process. This documentation shall include the following:

a. Plan for inspecting vendor supplied materials and a description of any equipment used to do so (with capabilities). A description of the record format is also required. See the mechanical requirements section of this document.

b. Documentation of the calibration of equipment/instruments used for inspection. Qualifications of the person(s) who will be performing the tests are also required.

c. Plan for obtaining and tracking material certifications. This includes (but is not limited to) foundry heat and chemistry reports (copper and 1006), annealing reports, as well as tracking of the annealed samples.

d. Testing plan for the coils (see section 2.2.6 and 2.2.8 of this document).

   Establishment of inspection points during the production process, which will measure critical parameters. These inspection points will be the previously described “hold points”. See the mechanical requirements section of this document.

- ❖ Jefferson Lab reserves the right to have its technical and/or procurement representatives witness any or all manufacturing steps, tests and inspections established under the Vendor’s quality assurance program.

Preliminary shipping and handling plans

The vendor shall submit a preliminary plan for all anticipated shipping of the tagger magnet component parts. This is to include shipment of the coils to the vendor’s facility if they are manufactured at another site, and final shipment of the tagger magnet to JLAB. Refer to section 3 (preparation for shipment) of this document for specific requirements.

1.5 Deliverables to JLAB after contract award

Labor and materials

The vendor shall, unless otherwise noted, furnish all labor, materials, equipment and facilities to fabricate, test, and deliver the Hall-D tagger magnet in accordance with this specification. Vendor is responsible for repairs, rework and/or delays caused by vendor or material supplier. The Tagger Magnet shall include the following:

- The magnet core assembly (composed of four plates) and associated fastening hardware as specified on drawings D00000-19-XXXX, and drawings D00000-19-00-1001 through D00000-19-00-1004.

- The normal conducting coils and associated mounting brackets and fittings as specified on drawings D00000-19-1005, D00000-19-00-1006 and D00000-19-00-YYYY.

❖ **All references to specific manufacturers products in this document shall have the following words appended to the requirement: "or Jefferson Lab approved equivalent".**

Manufacturing Records

A complete copy of all manufacturing records shall be provided to Jefferson lab. These records are described in more detail in the Quality Assurance Plan section. They are to include, but are not limited to, the following:

- Fastener certifications and documentation.

- Quality inspection reports as described in the Quality Assurance Plan. These reports are to be submitted to the JLAB technical representative for review. This will constitute a "hold point until JLAB acceptance. Inspection reports are to include but are not limited to: Inspection report upon receipt of vendor supplied materials to be used to fabricate the core pieces and coils. This shall include a defect report (see mechanical requirements section of this document) to be provided to JLAB prior to machining.

- Dimensional inspection reports to confirm compliance with the tolerances specified on the drawings.

- Material defects exposed during machining (voids and cracks) and a description of any proposed repair (see the mechanical requirements section of this document).

- Heat of material used for each core piece with the corresponding foundry chemistry report (see mechanical requirements section)

- Record of the annealing process for each core piece as well as a sample of the annealed material as described in the Technical Requirements section of this document.

1.6 Acceptance testing prior to shipping

The vendor shall perform acceptance tests as specified in section 2.2.8 before delivery to Jefferson Lab in accordance with and subject to all local safety regulations at the vendor. In the event the magnet fails the acceptance test the vendor is responsible for all material, labor, and shipping needed to repair and re-test the Tagger Magnet System.

- **Low conductivity water (LCW) is required for electrical operation of the coils. See section 2.2, table 3 for requirements.**

2 TECHNICAL REQUIREMENTS

2.1 MECHANICAL REQUIREMENTS FOR THE MAGNET CORES

2.1.1 Tagger Magnet Core Material

The core of the Tagger Magnet is to be constructed of SAE 1006 steel as specified in the table shown below. Steel that is ingot cast shall have a rolling reduction of at least three to one to reduce the probability of voids. Continuous cast material or steel produced by other processes that minimize voids, needs no reduction.

It is desirable that all core pieces are from the same heat, but this may not be possible. As a second option, the inner two plates (pole plates) should be from the same heat, and the top and bottom plates produced from a second heat. If more than two heats are required, this must be coordinated with JLAB to insure acceptable magnet performance.

- The foundry chemistry certification shall be provided to JLAB prior to beginning machining operations.
- The vendor shall provide copies of all tests results, ladle analysis, product analysis, material certification, and dimensional measurements to the Jefferson Lab Technical Representative within ten calendar days after obtaining such information, and not later than required by the Fabrication Milestones F-11 of Section **Error! Reference source not found.**.

Table 1: Chemical composition limits for SAE 1006 steel.

Impurity	**Wt.%**
Carbon	0.04 – 0.08
Manganese	0.25 – 0.45
Phosphorus	≤ 0.04
Silicon	≤ 0.4
Aluminum	≤ 0.03
Nitrogen	≤ 0.012
Oxygen	≤ 0.035
Sulfur	≤ 0.025
Copper	≤ 0.15
Nickel	≤ 0.15
Chromium	≤ 0.09
Molybdenum	≤ 0.07

2.1.2 Annealing of the magnet cores

All magnet core pieces shall be fully annealed after any cold work and/or prior to final machining. Steel shall not be handled or stored by lifting magnets or other magnetizing material at any time following the annealing process. In order to assure optimum magnetic performance, Jefferson Lab prescribes the following annealing cycle for a material similar to AISI-1006:

1. Choice of a suitable atmosphere (or vacuum) is left to the vendor and shall be addressed in the proposal.
2. Annealing temperature 1769 Fahrenheit
3. Hold piece at 1769 °F ±50 °F for one hour per inch of thickness.
4. Furnace-cool piece to 600 °F at a rate not to exceed 50 °F/hour, then air cool.

The vendor may propose a different annealing cycle if such a cycle would achieve equivalent or better magnetic performance for the material, but Jefferson Lab approval is required for any proposed annealing cycle. The vendor shall address the annealing cycle in the proposal.

After contract award any proposed change by the vendor in the annealing cycle shall require written approval from the Jefferson Lab Technical Representative. Jefferson Lab shall require ten calendar days after receipt of any proposed change to approve or disapprove it.

A sample piece of the 1006 steel from the heat shall be annealed along with every the slab being heat treated. The sample pieces of 1006 steel, 0.75 x 3 x 3 inches shall be extracted from excess volumes of the slabs. They shall be identified with the drawing number of the part they represent.

- The Jefferson Lab Technical Representative shall be provided with heat treatment records and the annealing sample for approval prior to final machining of the respective core piece. Jefferson Lab will respond within ten calendar days after receipt of documents.

2.1.3 Inspection of the core material for internal defects & sonic tests for voids cracks and inclusions

The vendor shall be responsible for the ultrasonic inspection of all pole pieces to assure delivery of steel free from discontinuities, bursts, pipes porosity, flakes, laps and seams. In order to determine the size, quantity, and location of any significant voids, non-metallic inclusions or discontinuities (lamina), the vendor shall ultrasonically inspect the entire volume of each pole piece in accordance with ASTM-A-578 with supplementary requirements of S1, S2 (acceptance as per S2.2- JLAB description below), S3, S4, S5, and S9, and provide the Jefferson Lab Technical Representative with a complete inspection record, including documentation of the inspector's qualification. **No calibration holes shall be drilled into the pole pieces. If calibration holes are required (S9), a separate scrape piece from the same heat may be used.**

In order to be "unconditionally acceptable", the ultrasonic inspection shall reveal no voids (or equivalent defects) with a characteristic diameter greater than 0.3 THIS IS UNREALISTIC inches throughout the steel core volume. Defects within 0.9 inches of the finished pole surface are not allowed, but a repair may be acceptable (see below).

Should a defect in a pole piece be discovered either by ultrasonic testing or exposed during machining, it shall be reported in writing (email is acceptable) to the Jefferson Lab Technical Representative. Jefferson Lab will determine within ten calendar days after receipt of documents (including any proposed repair technique) if the piece is acceptable, repairable, or is to be rejected. If a defect is close to the surface and deemed repairable, a press fit plug of the same core material (heat) may be used. **Welding is**

not permitted. If the piece is deemed "rejected" by Jefferson Lab it shall be replaced at the manufacturer's expense.

- The Jefferson Lab Technical Representative shall have the option to witness all ultrasonic inspections, and the vendor shall give the Jefferson Lab Technical Representative a minimum of ten calendar days notice as to the time and place of the inspections. The vendor shall demonstrate to the Jefferson Lab Technical Representative at the time of testing the ability of his equipment to detect deviations from the specifications of Section 2.1.3. The vendor shall also provide the Jefferson Lab Technical Representative with certifications of compliance with specifications (Section 2.1.3), and acceptance of the magnet shall be conditional upon compliance.

2.1.4 Work Hardening

In order to prevent deterioration of magnetic performance, the machining and drilling schedules to be followed after the pole material has been annealed shall be such as to avoid work hardening the pole material to a depth greater than 0.02 in. beneath the finished pole face surfaces and 0.05 in. beneath all other finished surfaces. For purposes of preparing these schedules the vendor may assume that work hardening for a properly ground sharp tool will extend to a depth equal to the thickness of the chip removed.

- Vendor shall provide a machining sequence to JLAB for approval to meet the above requirement.

2.1.5 Machining & Assembly Tolerances

All machining tolerances, pole profiles, and surface finishes and assembly tolerances are indicated on the JLAB design drawings. **No relaxation of these tolerances will be permitted without written permission from the Jefferson Lab Technical Representative**. All machining operations shall be carried out either with the work stabilized at a temperature of 70 °F ±5 °F or corrected to 70 °F. All finished yoke pieces shall be inspected and shall demonstrate compliance with the dimensional tolerances given in the manufacturing drawings. In the vendor's proposal, the vendor shall indicate how the yoke assemblies will be inspected. The Jefferson Lab Technical Representative shall have the option of witnessing the dimensional inspection. To this end, the vendor shall notify the Jefferson Lab Technical Representative at least ten calendar days in advance of the inspection.

2.1.6 Welding

Welding on the core assembly is not permitted.

2.1.7 Assembly- Clean area requirement

Assembly of core pieces shall be performed in a clean environment to assure no foreign particulates are trapped between mating surfaces. The presence of any such particulates that lead to a compromise in the geometric reproducibility of the assembly is cause for rejection. JLAB reserves the right to have the Technical Representative witness the magnet assembly at the vendor's facility. The vendor shall notify the Jefferson Lab Technical Representative at least ten calendar days in advance of assembly.

2.1.8 Protection

Interface surfaces between magnet core parts shall be lightly coated with the rust preventative LPS-3 or a Jefferson Lab approved equivalent. The surfaces of the core assembly that will be exposed once the magnet is assembled (not including the vacuum wetted surfaces or o-ring sealing surfaces) shall be cleaned, masked, primed and painted as noted on the details and Core Assembly Drawing. The vacuum wetted surfaces are to be coated with Cosmoline (or a JLAB approved equivalent). In addition, all assembly hardware (i.e. nuts, threaded rod, and dowel pins) and all threaded holes shall be masked during painting**. Interface surfaces and vacuum wetted surfaces are to be protected from mechanical damage**. Prior to painting, the core shall be cleaned of dusts, oils, rust, and other contaminants to assure a smooth and durable bond. The protectants to be used should be specified at the time of the proposal. Any change to this protection plan must be approved by the JLAB technical representative.

2.1.9 Marking

Each core component shall be marked on one side and on one end (not the interface or vacuum wetted surface) with its part number and weight in 3" tall painted numbers. These markings must be easily visible after painting.

2.2 COIL REQUIREMENTS INCLUDING LCW WATER AND POWER

The Tagger magnet normal conducting coils will be constructed from water cooled, hollow copper conductor windings. **Low conductivity water (LCW) is required for operation**. The coils must meet the requirements given in Table 2. The Tagger Dipole Magnet Coils are to be wound, without conductor-to-conductor joints, in a fashion which minimizes the heat transfer between cooling loops as demonstrated in drawings D00000-19-00-1005 and D00000-19-00-1006. The specification for the water fittings, temperature switches, and current connections are also specified on these drawings. The coil assembly is to be insulated from the ground potential using fiberglass supported epoxy (vacuum-pressure-impregnated fiberglass tapes and cloth).

Table 2: Partial list of coil requirements

Requirements	**Units**	**Value**
Coil Mechanical Requirements		Drawings D00000-19-00-2010 and D00000-19-00-2010 winding scheme, fittings, brazing, material. Flags, fittings and klixon should be on drawing.
Maximum Design Temperature	°F	203
Maximum operating temperature	°F	176
Maximum water pressure	PSI	120
Maximum water pressure drop	PSI	100 return line is at 20 psi?
Maximum flow rate	GPM	20
Maximum water flow velocity	ft/sec	8
Maximum voltage drop across all coils connected in series for 1.8 T	V	170
Maximum Current	I	400
Operating Current at 1.5 Tesla	I	223
Operating Current at 1.8 Tesla	I	320

2.2.1 Materials

Conductor Development Association Alloy # C10200 or Alloy # C10300 annealed (or JLAB approved equivalent) hollow copper conductor shall be used. Coil assemblies shall be fabricated without any conductor joints or splices.

2.2.2 Insulation

The conductor turns are to be insulated from each other with a **primary insulation** of Mylar tape and a **secondary insulation** of fiberglass tape. The coil assembly is to be insulated from electrical ground and bound in a stable configuration using a ground wrap of fiberglass tape. The entire assembly is vacuum impregnated with epoxy. Materials shall be rejected in the event that they have been shipped or stored improperly such that contamination, mechanical damage or degradation has taken place. No material shall be used that is beyond its published shelf life.

a. Primary conductor insulation
   The primary turn-to-turn insulation material shall be 3M #56 Mylar tape or a Jefferson Lab approved equivalent, 0.0022" thick by widths suited to half lap application by manual or machine methods.

b. Secondary conductor insulation
   Dry fiberglass tape, between 1/2" and 2" wide x .005" thick, in a medium or dense weave shall be used for the reinforcement of the epoxy around the individual conductors. Dry fiberglass tapes 0.007” thick, in a medium or dense weave shall be used for the reinforcement of the epoxy that forms the ground wrap. The fiberglass materials shall be “E” grade, treated with an epoxy compatible coupling agent.

c. Epoxy Formula

   The following formula is required for the vacuum impregnation of the coils.
   Formulation of Encapsulant (all in parts, per weight)

Shell EPON826 Resin	70
Shell EPON871 Resin (aliphatic polyepoxide) flexibilizer	30
	100 parts of resin

Where

Total (EEW) Epoxide Equivalent Weight is:	826 is .7(182)=127
	871 is .3(430)=129
	EEW = 256 (+/- 6%)

Plus
Uniroyal Chemical Co. TONOX (aromatic diamine curative)
Shell Agent-W or Agent-Y may be substituted for TONOX.
Total (HEW) Hydrogen Equivalent Weight is: 48(+/-4%)

$$\frac{\text{HEW}}{\text{EEW}} \quad \frac{48}{256} = \frac{20}{100} \quad \frac{\text{parts of C/A}}{\text{parts of resin blend}}$$

plus at the vendor's option:

Anchor Pacific K.54 Accelerator (Tris[Dimethyl Aminomethyl] Phenol)

$$= \frac{\frac{1}{2}}{100} \quad \frac{\text{parts of accelerator}}{\text{parts of resin blend}}$$

Cure Cycle:
2 hours at 80C, 3 hours at 150C, slow cool to 50C at 20C/hour

Other formulations will be considered if submitted with the proposal. Details of the alternate formulation; viscosity, pot life impregnation cycle, cure cycle and technical performance data such as mechanical strengths, hygroscopic behavior, and radiation resistance must be included, and provided to the JLAB technical representative. The vendor shall include a statement explaining the reasons for preference of the alternate formulation. The requirements for an alternate epoxy are listed below.

Requirements for alternate epoxy formulation:

Operating Temperature: 95 C
Thermal Cycle Life: 100 cycles/year for 20 years
Radiation Resistance: 1.3×10^5 rad
Color: clear, clarity to allow visual inspection of conductors
Hardness: 90 (Shore D)
Flexural Strength: 16,400 psi
Heat Deflection Temperature: 116 C
Viscosity: 25 cps at 80 C
Volume Resistivity: 1.24×10^{15} ohm-cm.

d. Insulation Clarity and Finish

Insulation shall be left as clear to allow for visual inspection of individual conductors. There shall be no powder fillers, no coloring or pigmentation used in the insulation system. There shall be no painting or refinishing of coil surfaces. Excess epoxy shall be removed/cleaned so dimensional tolerances are maintained.

2.2.3 Filler Blocks

Filler blocks shall be made from NEMA Grade G-10 or G-11.

2.2.4 Braze Filler Material

Joints between copper conductors and copper electrical terminals may be brazed with silver-copper-phosphorous braze alloy per Federal Specification QQ-B-654A,Grade BcuP-5 without flux (Handy and Harmon Silfos) or the system below. Joints between copper conductors and brass fittings shall be brazed with flux using preforms or filler materials that conform to Federal Specification QQ-B-654A,Grade Vii (Handy and Harmon Easy Flow 45). All traces of flux shall be removed before potting.

2.2.5 Coil Fabrication

No deviation from procedures proposed by the vendor (detailed in the Manufacturing Plan) will be allowed without prior written approval from the Jefferson Lab technical representative.

a. Conductor Inspection
The vendor shall inspect the conductor upon receipt. The inspection shall verify material certification, cross-section dimensions; freedom from excessive warp, twist and camber; freedom from slivers, burrs or other defects on the surface; freedom from bore obstructions such that the flow requirements, as specified in table 3 are not compromised.

b. Conductor Cleaning
The conductor shall be free of slivers, burrs, and other injurious defects. The conductor shall be cleaned and de-greased before application of insulating materials using a Jefferson Lab approved solvent and solvent cleaning method. Drying shall be performed with dry nitrogen or clean filtered (dry) air to avoid oil or water deposition on the cleaned surfaces.

- Insulation materials and clean conductor surfaces shall be protected from skin oil, etc., by requiring shop personnel to wear clean, lint free gloves while handling conductors and insulation. Cleaned conductors, whether bare or insulated, shall be stored and processed in an area free from metallic dust and other coil contaminants. Insulation and in-process subassemblies shall be stored and/or processed in controlled clean areas.

c. Coil Winding
The vendor shall include details of the coil winding procedure in his proposal as part of the manufacturing plan. The sequence of all activities shall be clearly indicated. No joints are allowed in the windings.

d. Turn-to-Turn Insulation
A single winding of Mylar tape primary insulation shall be applied to the conductor half-lapped.

For the turn-to-turn fiberglass epoxy insulation system a single winding of half-lapped, 0.005” thick fiberglass tape shall be applied directly over the Mylar tape. The distance between edges of the fiberglass tape may range from zero to 1/8 inch. Care

shall be taken to avoid damage to the insulation in subsequent handling. Damaged insulation shall be reapplied in a manner that will maintain insulation continuity.

e. Ground Wrap Insulation

One half-lapped layer of 0.007" fiberglass shall be wrapped around the straight lengths of the coil that form the body and around the straight ends of the coil that forms the cross-over.

More sparsely wound tape or cloth, suitably restrained, may be substituted in the 90 degree bend zones where excessive build-up on the small radius is expected. Care shall be taken to prevent damage to the insulation in subsequent handling. Damaged insulation shall be replaced in a manner that will maintain insulation continuity.

f. Braze Joints

No joints are allowed conductor-to-conductor in the body of the windings.

Braze Joint Sample for the Proposal

- A braze joint is specified in the enclosed drawings at the pipe fittings to the coils and from the conductor to flags. All brazes must adhere to ASME B31.9 Building Services Piping requirements. The vendor shall submit a representative sample of this joint with the proposal using a sample copper conductor that is within 0.15 inches of the specified copper in width and breadth and within 1/16 inch of the hole diameter. The vendor is required to submit a Brazing Procedure Specification with the sample braze. The sample will be sectioned and judged by the Jefferson Lab Proposal Review Board on the basis of leak tightness and freedom from flow restrictions. Disqualification of the sample braze joint is a basis for disqualification of the vendor's proposal for brazing.

Production Coil Braze Sample (as per ASME B31.9 Building Services Piping requirements)

- Before brazing the conductor-to-water fitting joints of production coils, the vendor shall submit to the Jefferson Lab technical representative, a sample of the braze joint using the actual copper used in the coil along with identification of the braze maker. All production personnel utilized as braze makers for the production coils must submit a sample of the braze joint. Jefferson Lab must approve the braze joint as acceptable prior to continuation of coil production work by the braze maker.

g. Fixtures for Potting and Curing

Each magnet coil shall be vacuum impregnated with epoxy and heat cured. It is the responsibility of the vendor to design and fabricate a mold that forms the coil to the required tolerances.

h. Impregnation and Curing Processes

a. Process Verification

The vendor shall verify in his manufacturing plan that impregnation and cure of the insulation system will use the materials and handling process parameters specified in this document and shall record all cure process times and temperatures and mm of vacuum associated with the following procedures:

b. Coil Preparation

The vendor shall dry the assembled coil in an oven prior to the vacuum impregnation process and shall certify the oven drying time and temperature in a preheated oven is 135°C. Following completion of the oven drying cycle, the assembled coil shall be allowed to cool down to 25°C prior to insertion in the mold. Once installed in the mold above, a dry vacuum shall be pulled for ~ 10 minutes at 2 to 5 mm of mercury. The coil lead fittings and flags shall be protected from contact with the epoxy during impregnation and curing.

c. De-aeration of Epoxy Resin Mixture

The epoxy system shall be placed in its holding tank at 25°C and de-aerated in accordance with the manufacturer's recommendation. The vendor shall note the time and mm of mercury required to de-air the epoxy and shall set aside a one pint sample of the de-aired epoxy system prior to vacuum impregnation and record the viscosity at 25°C using a viscometer and methodology recommended by the epoxy manufacturer. The vendor shall retain the sample; marked "Pre-impregnation" and identified by coil number, date and viscosity reading, for review by the Jefferson Lab technical representative and transported with the finished coil's documentation.

d. Impregnation and Cure

The coils shall be vacuum impregnated and cured in accordance with the manufacturer's recommendation. When the dry vacuum pulled on the mold is complete; flood the mold with de-aired epoxy from the holding tank and hold the vacuum until the coil impregnation is complete. Break vacuum and cure using a time and temperature sequence recommended by the resin manufacturer. The vendor shall record all times to, from and at temperature during the post impregnation cure cycle and cool down following cure. The vendor shall ensure that the coil has cooled to 25°C prior to removal from the mold. The vendor shall

note the time and mm of mercury required to vacuum impregnate the coil and shall set aside an additional liquid sample of the epoxy system following vacuum impregnation and record the viscosity at 25°C using a viscometer and methodology recommended by the epoxy manufacturer. The vendor shall retain the sample; marked "post impregnation" and identify by coil number, date and viscosity reading, for review by the Jefferson Lab SOTR and transport with the finished coil's Traveler. The vendor shall set aside a sample of "Post-impregnation" epoxy ~ 50 grams for cure hardened i**n a thin layer condition** along side of vacuum impregnated coil. The cured sample shall be marked with coil number and time and temperature; for review by the Jefferson Lab technical representative and transported with the finished coil's Traveler.

e. Removal from the mold
Flash shall be removed in such a way that no sharp edges remain on the coils. Removal of flash shall not puncture the insulation or damage the flags or water fittings.

i. Impregnation Evaluation and Repair
After the removal of flash, the vendor shall inspect the cured coil. The following conditions are not acceptable and the coil shall be rejected if these features are evident:

- Dry fiberglass or incomplete saturation of the fiberglass on the surface or within the coil
- Cracks on the surface or within the coil
- Areas of uncured resin.

The Jefferson Lab technical representative may consider repair of the above defects. Prior to repair the Vendor must submit to the Jefferson Lab's technical representative a non-conformance report with a specific, written, repair procedure, including specific electrical tests that match or exceed the requirements of this specification, Section 2.2.6. The request for permission to repair may be denied at the discretion of the Jefferson Lab's technical representative.

2.2.6 Coil Testing

Mechanical and electrical inspections and tests shall be performed on each coil **after the coils are manufactured and again after full assembly.** Copies of all satisfactory and signed-off test reports shall be provided. The Vendor shall submit their Test Plan, to include equipment, procedures and report format, with their proposal. The vendor shall

provide Jefferson Lab with sufficient advance notice to allow the witnessing of in-process and final acceptance inspections and tests by the Jefferson Lab technical representative.

- **Low conductivity water (LCW) is required for electrical operation of the coils. See section 2.2, table 3 for requirements.**

a. Water Circuit Test
   The water passage shall be flushed with a solution of trisodium phosphate (or a JLAB approved substitute if TSP would violate environmental laws) to clean the conductor bore of emulsions and other processing contaminants. After cleaning, potable water at a minimum of 30 psi shall be pumped through the coil, with a 50 to 150 micron size filter at the inlet. Flushing may end when no dirt or grease is deposited in an identical filter placed in the outlet stream for one minute.

b. Flow/Pressure Tests
   The coolant circuits shall be tested for flow and pressure drop and shall be subjected to a hydrostatic pressure test. These tests shall be performed using potable water. Flow Test inlet water temperature shall be 45 +/- 2 degrees Celsius. Flow test inlet pressure shall be 50 psi with a 30 psi minimum. Record flow (gpm) and pressure drop (psi) through each circuit. Coil-to-coil variations for identical circuits shall not exceed 5% and shall be within 10% of the expected flow when corrected for line pressure. Hydrostatic test pressure shall be 250 psi. There shall be no pressure drop, within the resolution of the pressure gage, during a 30 minute test of each water circuit. The pressure gage shall be accurate to better than 1 % over the range of 0-300 psi, and shall be graduated in not greater than 2 psi increments.

c. DC Resistance
   The DC resistance of each coil at a known temperature shall be measured and recorded, with +/- accuracy of 1 %, following the application of the fiberglass ground wall insulation. When repeated after the coil has been heat-cured, values, adjusted for temperature differential, shall agree within 2.5 %.

d. Induced Voltage/impulse Test
   A vendor proposed (and Jefferson Lab technical representative approved) induced voltage test for locating shorted turns, shall be employed to test each circuit both before and after the pressure/heat curing process. The induced voltage stress shall be at least 10 Volts/turn. An Impulse test of greater voltage per turn may be substituted for this test in each part of the process. There shall be no deviation in wave shape between any of the test oscillographs.

e. DC Hipot Tests
Following the induced voltage/impulse tests, establish an intimate Ground Plane and DC hipot each circuit at 4.8kV for one minute. Record the DC leakage current at the beginning of the test, at 30 and at 60 seconds. Breakdown shall be cause for rejection of the unit under test. Coils of the same style shall display leakage currents (at the 60 second interval) of similar magnitudes.

2.2.7 *The following procedure must be followed when the coils are shipped.*

a. Coil Identification
A removable nameplate shall be attached to the coil lead. Nameplate data shall include the vendor's name, coil weight, epoxy name, maximum test current, a unique unit serial number and the contract number. (After final magnet assembly the nameplates will be removed from the coil leads and permanently affixed to the magnet core.)
In addition, the lead end of each coil shall be permanently marked with the same unique serial number as is on the nameplate. That marking shall be done with non-magnetic materials.

b. Coil Packaging
The coolant passages shall be drained of all water, flushed with isopropyl alcohol to provide freeze protection for residual water, drained by being blown out with compressed air, and sealed for storage and subsequent shipment. Commercial plastic protectors made for this purpose shall protect fittings. Coils shall be crated for shipment to the “magnet assembly site”. The crates shall be built for handling with slings from overhead cranes and for forklift transport. Gross weight per crate shall not exceed 5 t. The crates shall protect the coils from damage in transit and from weather during transit and outdoor storage.

Each crate shall be marked with the addressee, shipper, contract number, contents and shipping weight. The vendor shall arrange shipping.

c. Coil Documentation
Documentation to be provided with each coil includes the manufacturing and quality records as previously described in the coil testing section 2.2.6. In addition, A visual Inspection report (including digital camera files) must be provided.

2.2.8 Acceptance Tests at the assembly facility

Coils manufactured off site will be subjected to acceptance testing at the vendor's facility. Copies of the coil factory inspection and test records shall have been shipped with the coils for purposes of identification and comparison. Failure to meet drawing and specification requirements will be considered sufficient cause for rejection. Fabrication acceptance tests shall include:

a. Dimensional Inspection
   A careful visual and quantitative dimensional inspection shall be made to verify conformance to drawing and specification requirements.
b. Testing
   The magnet coils will be subjected to replication of all tests described in Section 2.2.6 at the assembly facility **after assembly into the magnet cores**. After normalization to null out test condition differences, identical values are expected.

3 PREPARATION FOR SHIPMENT OF THE COMPLETE TAGGER MAGNET

Delivery shall be made to Thomas Jefferson National Accelerator Facility (JLAB), Hall-D, 12000 Jefferson Avenue, Newport News, Virginia USA. The vendor shall be responsible for all delivery arrangements from the vendor's Tagger Magnet System fabrication facility to Jefferson Lab Hall-D including shipping fixtures, special custom fabricated lifting devices, crating, packing, weather proofing, sea proofing and protection, customs clearance, customs duties if any, paid in full and local transportation costs into Jefferson Lab Hall-D. JLAB will apply for duty free entry.

The vendor's representative shall be present for the delivery, unloading and uncrating of the Tagger Magnet system. Jefferson Lab will provide unloading and uncrating services for the Tagger Magnet system at no cost to the vendor. The vendor shall be responsible for the delivery of the Tagger Magnet into Jefferson Lab Hall-D including full responsibility for coordination of the delivery date and time.

The tagger magnet installation is shown in interface drawing D00000-19-00-3001. The truck ramp to the tagger hall at JLAB was designed so that a 73.5' long semi-truck (Classification WB-65) can back to the door. The door is 14 ft 9 in high and 14 ft wide. The magnet is designed such that it can be assembled in place on the photon beam axis in the tagger hall using the lifting equipment foreseen for the hall. Due to this requirement, the maximum weight of any single assembly to be lifted in the hall is 25t which is the rating of the gantry crane over the tagger area. An animated computer movie file

XXXXXX is provided as part of this documentation package to clearly show the planned installation sequence.

4 DESIGN DOCUMENTS AND DRAWINGS

The Tagger Magnet Reference design consists of the following drawings shown in table 4. The drawings supplied with this specification are in US units.

Table 3: The Tagger Magnet System Design Drawing List

Drawing number	Sheets	Drawing Title
D00000-19-00-XXXX		Tagger Assembly Drawing showing plates, coils and hardware (tierods, bolts, coil brackets etc.)
D00000-19-00-1001		Magnet lower sub-assembly
D00000-19-00-1002		Magnet lower pole sub-assembly
D00000-19-00-1003		Magnet upper pole sub-assembly
D00000-19-00-1004		Magnet upper sub-assembly
D00000-10-00-YYYY		Coil attachment bracket sub-assembly
D00000-19-00-1005		Coil sub-assembly lower
D00000-19-00-1006		Coil sub-assembly upper
D00000-19-00-3001		TAGGER INTERFACE

4.1 Tagger Magnet Steel Core Assembly

This specification covers the reference design of the Tagger magnet core assemblies. Detailed specifications for the fabrication and machining and of the steel yoke/poles are given in the drawings D00000-19-00-1001 through D00000-19-00-1004. The magnet core is constructed from 4 large iron plates. These plates are held together with a combination of high tension rods and bolts shown on drawing D00000-19-00-XXXX.

4.2 Magnet Coil Design

The design for the normal conducting coils is detailed in drawings D00000-19-00-1005 and D00000-19-00-1006. The coil is manufactured as an array with 7 turns in the horizontal and 12 in vertical. The details of the winding scheme are shown in the above drawings. Alternate winding schemes are possible but they must also insure a minimum of heat exchange between the incoming and outgoing water paths. An alternate winding

scheme must be approved by the Jefferson Lab technical representative. The conductor is an 11 mm square hollow copper conductor with a Ø7 mm coolant hole. The edges of the conductor have a 1mm radius. One example of this conductor is the LUVATA model 8143 hollow copper conductor (www.luvata.com). Jefferson Lab requires that the water fittings specified in the above drawings be used. The placement of the water fittings, thermal switches, and surveying features may be changed at the vendor's request subject to approval by the JLAB technical representative. Any alternate design must include all necessary supports/attachments for the power and water connections. There should be no exposed conductors on the final assembled magnet.

4.3 Applicable Documents

The following documents are part of this specification. If any apparent conflict between the requirements of the reference documents and the specification is found, it shall be brought to the attention of the Jefferson Lab Technical Representative for resolution.

- ASME Code for Pressure Piping
  - B31.3 Process Piping
- Miscellaneous ASME Codes
  - Y14.5 Dimensioning and Tolerancing
- NEMA
  - NEMA Standards for Electrical Control 1C1-1954, latest revision, 155 East 44^{th} St., N.Y., N.Y., which shall constitute the minimum acceptable standards.
- Institute of Electrical and Electronics Engineers (IEEE)
  - All electrical equipment shall conform to the latest standards of the Institute of Electrical and Electronics Engineers (IEEE).
- ASTM
  - A578 Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications
- American Conference of Governmental Industrial Hygienists
  - Pamphlet ISBN: 1882417585 "Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposures Indices (2005)
- Miscellaneous
  - QQ-B-654A Federal Specification Brazing Alloys, Silver

5 FABRICATION MILESTONES

Milestone Number	Milestone	Months after receipt of order	Deliverables
F-1	Receipt of steel for magnet core	18	Inspection & Acceptance Report including material certification
F-2	Test results for magnet properties of steel	24	Test Report
F-3	Receipt of Copper conductor	12	Inspection & Acceptance Report including material certification
F-4	Winding Tooling Complete	18	Report
F-5	Coil winding and potting complete	24	Report
F-6	Coil acceptance test	24	Report-Witness Inspection
F-7	Heat Treatment Records	24	Report-Witness inspection
F-8	Magnet assembly inspection	26	Report–Witness inspection
F-9	Magnet Steel Ultrasound Inspection	20	Report –Witness inspection
F-10	Magnet Steel Complete	26	Report
F-11	Magnet System Complete	28	Report

F-12	Factory Tests complete	28	Report-Witness Inspection

5.1 ACCEPTANCE TESTING AND DELIVERY MILESTONES

Milestone Number	Milestone	Months ARO	Deliverables
AT&D-4	Acceptance Test Readiness Review at JLAB	28	Acceptance Test Plan Reviewers Report from JLAB
AT&D-5	Magnet Acceptance	31	Certificate from JLAB

Figure 1. Hall-D electron tagging spectrometer. Shown are the Tagger Magnet, vacuum chamber, supports, and the detector packages. This specification covers the Tagger magnet only. Other components are shown for reference and delivery planning.

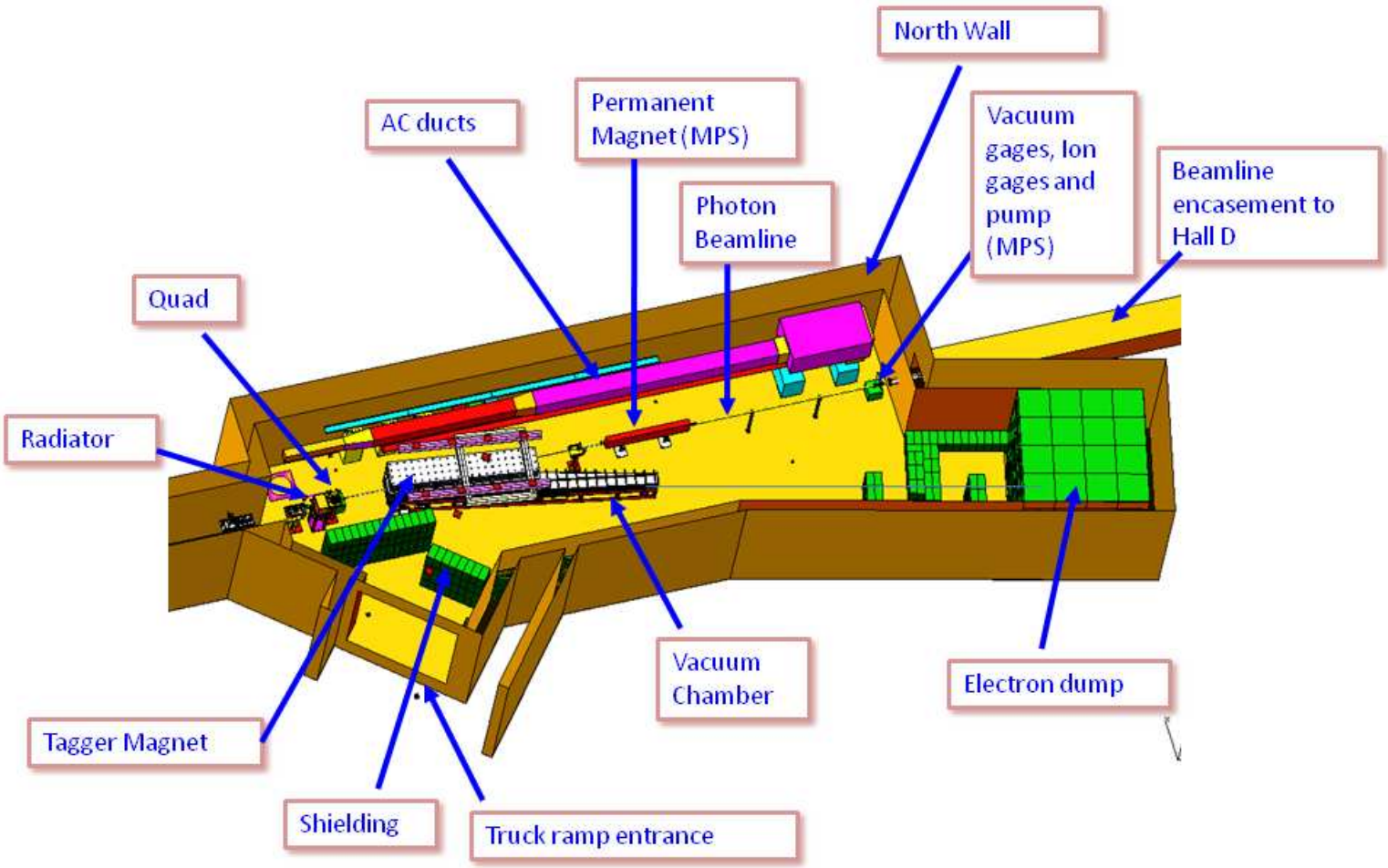

Figure 2. Components included in this specification: The four plates of the magnetic core and the normal conducting coils, as well as assembly mounting hardware.

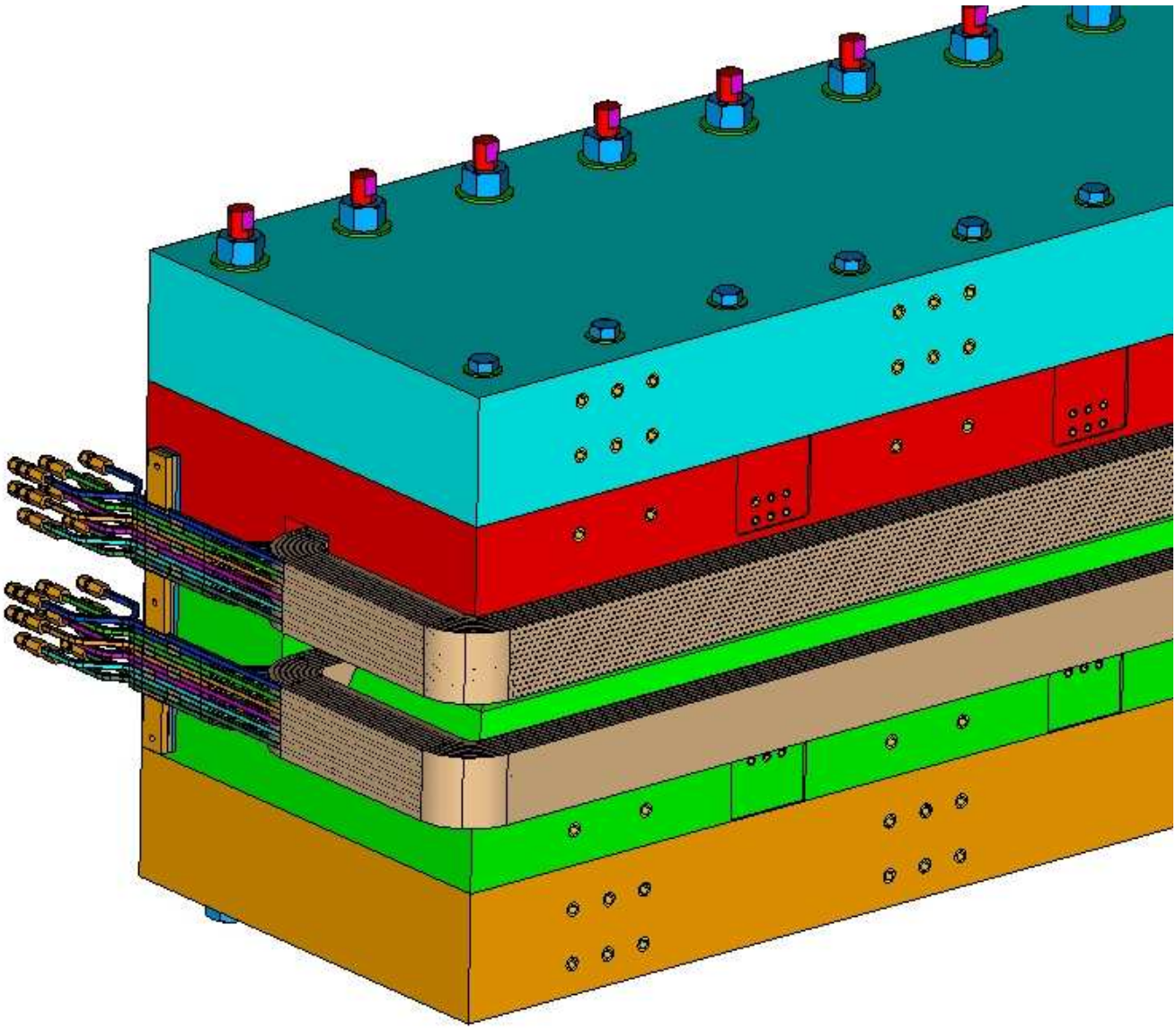

Figure 3. Cross sectional view of the components included in this specification. The coil support brackets are removed from clarity, but are part of the requirement.