

Specification for Current Limiting Reactors - NSTX-U PF1B Coil

Technical specification: NSTXU_1-5-3-3-5_SPEC_100

REVISION 0

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P.O. BOX 451
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TECHNICAL SPECIFICATIONS

FOR

CURRENT LIMITING REACTORS

(NSTX-U PF1B Coil Circuits)

CAT: A2

NSTXU_1-5-3-3-5_SPEC_100

REVISION 0

Reference Work Planning # 2137

DATED October 31, 2019

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PRINCETON PLASMA PHYSICS LABORATORY

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609-243-2000

1.0 INTRODUCTION & SCOPE

- 1.1 Princeton Plasma Physics Laboratory (PPPL), on Princeton University's Forrestal Campus in Plainsboro, N.J., is devoted to understanding the physics of plasmas and to developing practical solutions for the creation of fusion energy. PPPL is managed by Princeton University for the U.S. Department of Energy's Office of Science, which is the largest single sponsor of basic research in the physical sciences in the United States.
- 1.2 This specification covers the performance, requirements, and general design and construction features of dry-type, air core, series-connected current limiting reactors to be used in the PF1B pulsed power circuits of the NSTX-U rectifier power supplies. A total of 3 reactor stacks are to be provided. One reactor stack shall contain 2 x 2.5mH reactors and the two other reactor stacks shall contain 2 x .27mH reactors. This document is not intended to specify completely all the details of reactor design and construction, but to define PPPL specific technical requirements and other design constraints. Equipment shall be constructed and equipped with accessories in accordance with Supplier's standard practices when such practices do not conflict with this specification. Equipment shall, as a minimum, conform to acceptable industry standards for modern engineering design and workmanship.

2.0 APPLICABLE DOCUMENTS

The codes and standards listed below shall be considered part of this Specification. The latest revision in effect on the date of this Specification shall apply to all codes and standards referenced.

- 2.1 IEEE/ANSI C57.16-2011 - IEEE Standard for Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors
- 2.2 ANSI/NEMA C29 - Electrical Power Insulator Standards
- 2.3 National Electrical Safety Code (NESC) 2017
- 2.4 National Fire Protection Association (NFPA) 70-2017, National Electrical Code
- 2.5 ANSI/NEMA CC 1- 2009 Electric Power Connection for Substations

3.0 APPLICABLE DRAWINGS

Not applicable

4.0 RESPONSIBILITIES

4.1 PRINCETON PLASMA PHYSICS LABORATORY

- 4.1.1 PPPL shall designate a technical contact, the Princeton Technical Representative (PTR) and a Quality Assurance (QA) contact at the time of the award. All communications on administrative matters shall be directed to the PPPL Procurement Representative.
- 4.1.2 The PTR or Authorized Person will coordinate all work by the Subcontractor on-site, including scheduling, de-energizing, equipment staging, and site access authorization for Subcontractor personnel and equipment. (PTR) to minimize systems down time and shall not have any negative impact on experimental operations.
- 4.1.3 All communications on technical matters shall be directed to the assigned PTR.
- 4.1.4 All communications on administrative matters shall be directed to the PPPL Procurement Representative.

4.2 SUBCONTRACTOR

- 4.2.1 The supplier shall advise PPPL of the codes, specifications, and standards complied with in the design and manufacture of this equipment.
- 4.2.2 The supplier shall provide a test plan which sequences and details all of the testing required as per 6.2.
- 4.2.3 The supplier shall provide a design calculation package describing the electrical, mechanical, and thermal considerations used in the reactor design for the pulsed and short circuit loads described in Section 5. Any margins used shall also be described.
- 4.2.4 The supplier shall provide outline drawings of the reactors, including overall dimensions, location of input and output connections, estimated weights, and anchoring details. The terminals for PPPL's external connections shall be clearly located and dimensioned. Drawings shall be stamped by a Professional Engineer.
- 4.2.5 The supplier shall provide a Bill of Materials listing all components by type and general description.
- 4.2.6 The Subcontractor shall provide a single point of contact for any communication between PPPL and the Subcontractor.

5.0 REQUIREMENTS

5.1 PERFORMANCE REQUIREMENTS

5.1.1 PERFORMANCE CHARACTERISTICS

Each reactor shall be designed and constructed to meet the requirements in Table 1

TABLE 1 – Performance Characteristics

Reactor #1 (mH): (1 stack, each with 2 x 2.5 mH)	
Impedance at 60 Hz (ohms) for 2.5 mH	0.943 Ω
Reactor #2 (mH): (2 stacks, each with 2 x 0.27mH)	
Impedance at 60 Hz (ohms) for 0.27 mH	0.102 Ω
X/R Ratio (Minimum at 60 Hz)	>100
Continuous current rating (kA, 80°C rise)	1.0 kA
Peak short circuit current (kA)	
2.5 mH:	23.2 kA
0.27 mH	64 kA
Short circuit I ² t (A ² – sec)	
2.5 mH	4.85 x 10 ⁸ A ² -sec
0.27 mH	5.05 x 10 ⁸ A ² -sec
Maximum di/dt (Amps/μ-Sec)	2.0 A/μ-Sec
Guaranteed total losses (kW continuous, 80°C rise)	< 10.0 kW
AC insulation class (kV):	5.0 kV
B.I.L. (kV)	60.0 kV
Peak Pulse current (kA)	21.0 kA
Equivalent pulse duration (sec)	2.0 seconds
Pulse repetition period (sec)	1,200 Seconds
Number of repetitions	20,000

- 5.1.2 The reactors shall be designed to carry the pulsed DC currents and continuous currents as described in 5.1.1 with a winding temperature rise not exceeding 80° C. Because the actual operating currents are complex in nature, they have been expressed in terms of peak currents and time durations which reflect the RMS values of the actual waveforms. The reactors shall operate without damage at any current level from the continuous current to the peak pulse current listed in 5.1.1 with time durations consistent with their thermal ratings.
- 5.1.3 The reactors shall be capable of withstanding without damage the mechanical and thermal stresses caused by 100 short circuits faults as described in 5.1.1.
- 5.1.4 Under certain continuous operating conditions the reactor current will consist of a D.C. component plus a superimposed (approximately sinusoidal) ripple current, not in excess of 0.5 kA (peak), with a frequency variable between 720 and 1050 Hz. Ripple current frequency range is based upon 12-pulse rectifier powered by a motor-generator (MG) operating between 60 Hz and 87.5 Hz. The current ratings defined in 5.1.1 include the contribution of this ripple current to the load current.
- 5.1.5 OPERATING ENVIRONMENT

The reactors will be located indoors, in the Field Coil Power Conversion Building and will normally be subject to the environmental conditions as defined in Table 1.

Table 2 – Environmental Conditions

Ambient Temperature Range	50°F to 105°F (10° C to 40° C)
Relative Humidity	to 100%
Altitude	to 100 ft. above sea level
Background radiation	None
Seismic, vibrational, or shock forces	None
External magnetic field	Negligible

5.1.6 DESIGN LIFE

The reactors shall be designed for a 20-year life, during which they shall be subjected to 20,000 full current pulses and at least 100 short circuit faults.

5.1.7 RELIABILITY

Not Applicable

5.1.8 MAINTAINABILITY

Not Applicable

5.1.9 HUMAN FACTORS

Not Applicable

5.1.10 SUSTAINABILITY

Not Applicable

5.2 EQUIPMENT DEFINITION

5.2.1 SPECIFICATIONS AND STANDARDS

The reactors provided shall meet the requirements of, and shall be tested and evaluated to, IEEE/ANSI C57.16-2011 - IEEE Standard for Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors.

5.2.2 GENERAL DESIGN FEATURES

- 5.2.2.1 The cooling method for the reactors, specified herein, is by natural air convection.
- 5.2.2.2 The reactor windings shall be of either copper or aluminum and shall be insulated with class B insulation consisting of woven glass tape or continuous filament fiberglass impregnated with phenolic varnish or polyester or epoxy resin.
- 5.2.2.3 The windings shall either be supported in non-hygroscopic cleats or encapsulated in polyester or epoxy resin. If concrete supports are used, they shall not come into intimate contact with the windings.
- 5.2.2.4 Non-magnetic materials shall be used throughout the construction.
- 5.2.2.5 All equipment shall be designed so that eddy current losses are minimized.
- 5.2.2.6 All joints and splices shall be either brazed or welded. All conductors shall be smoothed to remove burrs and slivers before the insulation is applied.
- 5.2.2.7 The reactors shall be mounted on either porcelain or cast epoxy insulators.

- 5.2.2.8 If porcelain is used, it shall be manufactured by the wet-process method in compliance with ANSI C.29 and shall be free of any defects which might impair its mechanical strength or insulating characteristics.
- 5.2.2.9 The internal stresses in the insulators shall not exceed 50 percent of the components' ultimate mechanical strength.
- 5.2.2.10 The supplier shall supply all identical, interchangeable insulators. Each insulator shall have adequate height and strength to provide proper magnetic and electrical clearances to floor steel structures.
- 5.2.2.11 The reactors shall be furnished with lifting lugs or eye bolts suitable for use with crane slings.
- 5.2.2.12 The reactors will be open-type in groups of two, stacked vertically. The maximum allowable floor area for each reactor is six feet by six feet (6' x 6').
- 5.2.2.13 The reactors in a stacked set shall have the same winding orientation.
- 5.2.2.14 The maximum allowable height of two identical reactors stacked vertically, including terminals, is ten feet, zero inches (10'- 0").
- 5.2.2.15 A reactor assembly copper grounding bus shall be provided for each reactor stack. Grounding bus shall be at least (1/4 inch by 1inch) and furnished with compression type connector compatible with PPPL's No. 4/0 AWG copper grounding cable.
- 5.2.2.16 For external connections, the reactor terminal leads shall be routed to the top of a side of the two stacked reactors with standard bus assemblies consisting of copper bars supported by insulators mounted on rigid channels.
- 5.2.2.17 The supplier shall provide external terminals at the top of a side of the reactors with standard bus assemblies consisting of copper bus bars supported by securely mounted insulators. The terminal pads for the .27mH stacks shall be designed for connection of four (4) power cables at each of the two terminals of each reactor. The terminal pads for the 2.5mH stack shall be designed for connection of two (2) power cables at each of the two terminals of each reactor. The terminal pads shall accept the PPPL furnished cables with NEMA CC 1 two-hole compression-type cable lugs. The terminal pads provided will be 3 inches center-to-center. The terminal pads provided shall withstand the maximum mechanical forces generated during the pulse loading.

5.2.2.18 The minimum clearances required for spacing the reactors shall be shown in the Supplier's drawings and must be consistent with PPPL's maximum space allowance. PPPL requires that for moving the reactors into final installation location, the reactors must fit through an opening that is 5 feet, zero inches (5'- 0").

5.2.3 MATERIALS

After fabrication, all manufacturing waste shall be removed from the reactor assemblies. All grease, chalk, crayon, paint marks, and other deleterious material shall be removed from interior and exterior surfaces. At time of shipment, equipment shall be clean; inside and outside.

5.2.4 ELECTROMAGNETIC INTERFERENCE AND SUSCEPTIBILITY

Not Applicable

5.2.5 IDENTIFICATION AND MARKING

5.2.5.1 The nameplate shall be of not less than 20 gauge non-corrosive metal and shall include the following information:

- Identification or Serial Number
- Contract Number
- Rated reactance (ohms)
- Continuous current
- Insulation voltage rating ____ kV
- Thermal _____ kA _____ s
- Total weight ____ lbs
- Peak short circuit current _____ kA
- Basic impulse insulation level (BIL)
- Rated Inductance (Henries)

5.2.5.2 The winding orientation (as per 5.2.2.13) for each reactor in a stack shall be indicated on the unit.

6.0 **TEST & INSPECTION REQUIREMENTS**

6.1 PERFORMANCE TESTS

Not Applicable

6.2 ACCEPTANCE TESTS

6.2.1 The reactors must have a mechanical and thermal short circuit rating developed by formulation as outlined in IEEE/ANSI C57.16-5.6. See 5.1.1 for values.

- 6.2.2 Mechanical short-circuit test and mechanical strength capability as outlined in IEEE/ANSI C57.16-10.4. "The test for the mechanical strength capability of the series (current-limiting) reactor shall be made at a specified test current for a duration of not less than 10 cycles at rated frequency with the first maximum peak value of the completely offset short circuit not less than the maximum peak value given in [C57.16] 10.2.2 or as specified by the PPPL."
- 6.2.3 In lieu of the Mechanical Strength Test called out in 6.2.1, the supplier may present documentation of previous testing on a similar reactor design. Adequacy of such documentation as a substitution for paragraph 4.2 shall be judged by PPPL.
- 6.2.4 Each fully assembled reactor pair and enclosure shall receive all "routine" acceptance tests as outlined in IEEE/ANSI C57.16-6., Table 3:
- Direct current (DC) resistance measurement
 - Impedance measurement
 - Total loss measurement
 - Turn-to-turn test
- 6.2.5 The measurement of losses and impedance shall be as specified in IEEE/ANSI C57.16 -11.4.
- 6.2.6 Certified test reports shall be furnished for all of the above tests. Each reactor shall pass all required tests prior to being accepted by PPPL for shipment.
- 6.2.7 In the event of any acceptance test failure, Supplier shall notify PPPL immediately to determine the next course of action.

6.3 SUPPLIER HOLD POINTS

Not Applicable

6.4 QUALITY CONTROL RECEIPT INSPECTIONS

- 6.4.1 PPPL will perform Receiving Inspection on the reactors supplied by the supplier, using either a sampling plan or 100% inspection. Inspection shall be performed to determine compliance with outline drawings and technical specifications. Discrepant items will be rejected and returned to the supplier or reworked by PPPL.

- 6.4.2 PPPL's receipt inspection activities may include, but are not limited to:
 - 6.4.2.1 Dimensional inspection
 - 6.4.2.2 Functional and operational testing
 - 6.4.2.3 Comparison of the manufacturer's test reports to applicable specification requirements
 - 6.4.2.4 Visual inspection for evidence of used or reworked components, parts, or materials.

7.0 QUALIFICATIONS

The supplier shall provide documentation that the individuals fabricating the reactors have completed training and/or are certified.

8.0 ENVIRONMENT, SAFETY, AND HEALTH

The Quality Assurance Program shall require that all of Supplier's activities take into account environmental, safety, and health requirements with respect to personnel, and generation and disposal of hazardous waste.

9.0 QUALITY ASSURANCE REQUIREMENTS

9.1 Subcontractor's Responsibility for Conformance

Neither PPPL's review and/or approval of Subcontractor's documents nor PPPL's inspection of Subcontractor's items or services shall relieve the Subcontractor of responsibility for full compliance with requirements of the purchase order/contract. The Subcontractor is responsible for assuring that all requirements and restrictions are imposed on any sub-tier suppliers.

9.2 Changes to PPPL Approved Documents

Revisions or changes by the Subcontractor to documents approved by PPPL shall be reviewed and approved by PPPL prior to use.

9.3 Subcontractor Quality Assurance Program

9.3.1 The Subcontractor shall establish and maintain an effective Quality Assurance Program to assure that the Subcontractor's work meets the required level of quality and is performed in accordance with contractual requirements.

9.3.2 Subcontractor's quality assurance function shall be organized to have sufficient authority and independence to identify quality problems, verify conformance of supplied items or services to specified requirements and obtain satisfactory resolution of conflicts involving quality.

9.3.3 Subcontractor shall perform planned, periodic audits of the various aspects of its QA Program by persons not directly responsible for the area being audited. Written reports of these audits shall be available to PPPL.

9.4 Non-conformance & Corrective Actions and Notification

Non-conforming items or services shall be identified, and, where possible, segregated to prevent use. The Subcontractor shall document each nonconformance. The written approval of PPPL is required prior to the use of the nonconforming item or service. The Subcontractor's system shall provide not only for timely resolution of non-conformances but also for analysis of non-conformances to determine causes and to implement appropriate corrective actions (determination of cause and corrective action may be waived by PPPL for specific situations).

9.5 Submittal of Manufacturing/ Inspection/Test (MIT) Plan

9.5.1 The Subcontractor shall submit the Plan within 10 working days after receipt of the subcontract for PPPL approval prior to start of manufacturing. The plan shall identify parts; show their integrated flow into end items; identify critical manufacturing operations; and show inspections and the characteristics/dimensions to be inspected. The Plan may include flow chart(s), Process Sheets, Shop Travelers, and inspection sheets, etc. PPPL may designate selected operations as mandatory "witness" points based on the MIT Plan. Subcontractor shall provide PPPL with notice five working days in advance of such witness points. Revisions or changes to the approved MIT shall be reviewed and approved by PPPL prior to use.

9.6 Measuring Equipment / Calibration

Acceptance inspections and tests shall be performed using properly calibrated measuring equipment. Calibration standards shall be traceable to the National Institute for Standards and Technology (NIST) or equivalent. Where such standards do not exist, the basis used for calibration shall be documented. Standards used for calibration shall not be used for shop inspections and shall be protected against damage or degradation.

9.7 Submittal of Instruction Manuals

Subcontractor shall provide PPPL with an instruction manual describing instructions for receipt, installation, operation, maintenance, testing and repair of the supplied equipment.

9.8 Equipment/Material Identification and Status

9.8.1 Material and equipment identification shall be maintained throughout processing and be traceable to the records. Status of acceptability shall be readily discernible through the Subcontractor's use of tags, stamps, serial numbers or other positive means.

9.9 Fasteners

9.9.1 Subcontractor shall provide high strength fasteners (tensile strength equal to or greater than 100ksi) in accordance with the Fastener Quality Act. Fasteners shall exhibit grade marks and the manufacturer's identification symbol (headstamp) as specified in the referenced Material Specification. Fasteners having a headmark shown on the suspect fastener list shown in Attachment 1, will not be accepted. Certified Material Test Reports (CMTR), showing actual material composition and physical properties and traceable to the actual fasteners, are required for each lot supplied. Results must be on the original letterhead of the entity performing the tests and not transferred to alternate letterhead. Where high strength fasteners are not required, it is recommended that they not be used. If used, the requirements above shall be implemented.

9.10 Submittal of Completed Release for Shipment Form

9.10.1 Subcontractor shall not ship without a "Product Quality Certification and Shipping Release" Form (Attachment 2) signed by PPPL's Representative. Subcontractor shall complete and sign the certification section, fax or email the form to PPPL's Quality Assurance (QA) Representative, and hold shipment until PPPL signs and returns the form, authorizing shipment. A copy of the fully executed form shall accompany each full or partial shipment.

10.0 SHIPPING, STORAGE AND HANDLING

10.1 Subcontractor shall control items during handling and shipping and while in storage to assure that materials and items are adequately protected from damage or deteriorations, with special attention to packaging for shipment to PPPL. Packaging, shipping and storage systems shall provide adequate marking or labeling to clearly and readily identify the items.

11.0 WARRANTY

11.1 Seller shall provide warranty for the period (whichever expires earlier) as follows:

11.1.1 Eighteen (18) months from date of shipment, or

11.1.2 Twelve (12) months from date of operation.

12.0 ATTACHMENTS

Attachment 1 – DOE Fastener Headmark List

Attachment 2 – PPPL Product Quality Certification & Shipping Release

13.0 DOCUMENTATION & DELIVERABLES

Deliverables List

PO / Subcontract / BOA / BPA #: _____

#	Physical Deliverables Required	When Deliverable Is Required	Deliverable Received (✓)
1	One stacked reactor composed of 2 x 2.5mH	After shipping release is authorized	
2	Two stacked reactors, each composed of 2 x .27mH	After shipping release is authorized	
Exceptions (Add justification for any missing physical deliverables that will not be received):			

#	Document Deliverables Required	When Deliverable Is Required	Deliverable format (paper, electronic etc.)	Storage Location for Deliverable	Deliverable Received (✓)
1	Test Plan (4.2.2)	Prior to manufacturing	Electronic, PDF format	Ops Center	
2	Design calculation package (4.2.3)	Prior to manufacturing	Electronic, PDF format	Ops Center	
3	Outline drawings (4.2.4)	Prior to manufacturing	Electronic, PDF format	Ops Center	
4	Bill of Materials (4.2.5)	Prior to manufacturing	Electronic, PDF format	Ops Center	
5	Qualifications documentation (7.0)	Upon receipt of order	Electronic, PDF format	Ops Center	
6	Certified Test Reports (6.2.6)	Prior to release for shipment	Electronic, PDF format	Ops Center	
7	Certified Material Test Reports for high strength fasteners (as required) (9.9)	Prior to release for shipment	Electronic, PDF format	Ops Center	
8	Instruction Manuals (9.7)	Prior to release for shipment	Electronic, PDF format	Ops Center	
9	Product Quality Certification & Shipping Release (9.10)	Prior to release for shipment	Electronic, PDF format	Ops Center	

Princeton Technical Representative: _____

(Sign-off and provide to the Operations Center when job is completed and deliverables are dispositioned and placed/filed in Operations Center (or other Project, Department or Division designated file center)

Attachment 1

ANY BOLT ON THIS LIST SHOULD BE TREATED AS DEFECTIVE WITHOUT FURTHER TESTING

DOE HEADMARK LIST



ALL GRADE 5 AND GRADE 8 FASTENERS WHICH DO NOT BEAR ANY MANUFACTURERS' HEADMARKS

 Grade 5  Grade 8

GRADE 5 FASTENERS WITH THE FOLLOWING MANUFACTURERS' HEADMARKS:

	MARK J		MARK KS
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GRADE 8 FASTENERS WITH THE FOLLOWING MANUFACTURERS' HEADMARKS:

	MARK A		MARK KS
	MARK NF		MARK RT
	MARK H		MARK FM
	MARK M		MARK KY
	MARK MS		MARK J
	Hollow Triangle (CA TW JP YU) (Greater than 1/2 inch dia)		
	MARK E		MARK UNY

GRADE 8.2 FASTENERS WITH THE FOLLOWING HEADMARKS:

	MARK KS
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GRADE A325 FASTENERS WITH THE FOLLOWING HEADMARKS:

Type 1		MARK A325 KS
Type 2		
Type 3		

Headmarkings are usually raised – sometimes indented.
KEY: CA-Canada, JP-Japan, TW-Taiwan, YU-Yugoslavia

Reference: This tool was derived from the U.S. Customs Service.

Dated: 1992

**ATTACHMENT 2
PRINCETON UNIVERSITY PLASMA PHYSICS LABORATORY—PPPL
PRODUCT QUALITY CERTIFICATION & SHIPPING RELEASE**

**To be completed by supplier and submitted to PPPL with the Documentation package.
Shipment (full or partial) is not authorized until PPPL returns this form signed.**

Completed by Supplier	PPPL SUBCONTRACT/ ORDER #	ITEM #(s)	QUANTITY SHIPPED
	ITEM DESCRIPTION	SUPPLIER REFERENCE #	SHIPMENT #
	SUPPLIER'S CERTIFICATION		
<p>This is to certify that the products and services identified herein have been produced under a controlled quality assurance program and are in conformance with the procurement requirements including applicable codes, standards and specifications as identified in the above-referenced documents unless noted below. Any supporting documentation will be retained in accordance with the procurement requirements.</p> <p>SIGNED: _____ DATE: _____</p> <p>TITLE: _____ COMPANY: _____</p>			

Completed, signed, and returned by PPPL before shipment	PPPL (AUTHORIZED REPRESENTATIVE) SHIPPING RELEASE	
	<p>This is to certify that evidence supporting the above Supplier's Certification statement has been reviewed and no product/service nonconformances from procurement requirements have been identified unless noted below. This product/service is hereby released for shipment.</p> <p>This section serves as the Quality Assurance release for the above described product for shipment. It does not constitute an acceptance thereof and does not relieve the Supplier, Manufacturer or Contractor of any and all responsibility or obligation imposed by the purchase contract. It does not waive any rights the Purchaser may have under the purchase contract, including the Purchaser's right to reject the above described material upon discovery of any deviations from requirements of the purchase contract, drawings and specifications.</p>	
	NONCONFORMANCES FROM PROCUREMENT QUALITY REQUIREMENTS:	
	REMARKS/PRODUCT SERIAL NUMBERS:	
	BY PPPL QA REPRESENTATIVE (OR DESIGNEE)	DATE