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Facility Requirements to Test and Demonstrate a 6 MW Plasma Torch

M. C. Jackson and E. B. Hooper
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Background

Lawrence Livermore Laboratory has been approached by Plasma Technology Corporation (PTC) of Raleigh, North Carolina to assess technical and resource issues for a test/demonstration facility for proving the performance of a 6 MW plasma torch. This torch will be used as a possible heat source for vitrification, incineration, metal processing, etc. A torch of this size has never been built or operated. The facility would therefore be used to check torch parameters and components, to run a series of tests until the torch operation is demonstrated, and to show possible outside users the capabilities of the torch. This report is a summary of the facility requirements which would be needed if LLNL were to participate.

In brief, the plasma torch shown in Figure 1, consists of copper electrodes that are centered in a tubular, water-cooled nozzle constricted at the tip to form a narrow passage. Air is introduced into the nozzle, past the electrode, through the constricted passage. The arc generated from the rear electrode terminates on the target in the transferred mode and terminates back unto the torch in the case of the nontransferred mode. The unit is capable of generating arc temperatures of approximately 12,500°C. The parameters for the torch are listed in Table 1.

To meet these requirements the torch requires an array of auxiliary equipment. The equipment for a previous installation is shown in Figure 2. All the equipment shown in this figure would be required for this application, except for the heat exchanger. In this application the cooling for the heated water returning from the torch will be the main LLNL cooling towers. The pressure in the plant LCW will be increased by the pump station from the nominal 100 psig to 200 psig to match the necessary input pressure and returned to the plant cooling towers at the standard return pressure. The implementation of this and the rest of the facility for testing the torch is described in the following sections.

Implementation

The key to the implementation of this testing is finding a site that has ample power and cooling water to meet the requirements for this torch that are listed in Table 1. The site that best meets these requirements is the Mirror Fusion Test Facility (MFTF) cryogenic building. This building on the LLNL site is designated as B433 and the existing building configuration is shown in Figure 3. As can be

MASTER

Air Flow	250 to 300 scfm @ 100 psi
Power	6 MW DC
Current	3000A DC
Water	200 gpm @ 200 psig
Layout	torch @ 60° from horizontal
Noise	63 db
Target	24 inch graphite block
Electrodes	Copper (3 to 7% chromium ¹) or Copper (3 to 7% zirconium)
Arc	10.5 to 12 Volts/cm along length
Cathode Voltage Drop	4 to 5 Volts
Peak Temperature	12,500°C
Exhaust Gas Temperature	7000°C
Arc Attachment Point Temp.	7000°C
Energy Deposition	90% into gas (heat & radiation) 10% into torch body
UV	9% energy in UV radiation
Arc Viewing	#12 welding goggles

Table 1

seen in this figure, the building houses several large helium and nitrogen compressors. The equipment on the right (east) side of the building is to be removed for this installation. This equipment includes the three first stage compressors, the two second stage compressors, the forced flow compressor, and the purifier. This cleanout process includes removing the electrical, LCW plumbing, gas plumbing, sealing the gas plumbing in the building and on the compressors, and filling this plumbing with dry nitrogen. At this point, the oil can be removed from the compressors, disposed of and then the compressors removed. This removal involves removing sections of the roof and filling in between the compressor foundations so that the compressors can be slid out of the roll up door on the bottom right hand (southeast) corner of the building shown in Figure 3. The compressors can then be properly stored for later future use. The removal of this equipment leaves the individual foundation pads that the equipment set on sticking up from the building floor. These isolated foundation pads can be seen in Figure 4 and they rise above the building floor an average of 4 inches. These foundations make it very difficult to set equipment and walk around. The solution to this problem is to install forms between the

¹ See Appendix. It is recommended that this option not be used.

foundations and backfill with concrete. This process creates two large foundations shown in Figure 5.

The equipment shown schematically in Figure 2 can be installed on the newly created foundations as shown in Figure 6. This placement fits well with the building layout and the facilities needed for the torch operation. The power supply which supplies the 3 kA DC to the torch is located on the upper left section of these foundations. This places the power supply closest to the source of power immediately to the north of this section of the building. The water/gas flow is from the bottom left from the air compressor and cooling water pump station toward the top of the page (northerly) where they combine with the power and proceed to the torch. The torch/load area and the control panel will be located on the other foundation. This allows the load to be located near the eastern wall which allows the exhaust gases to exit the building and up the stack. This configuration also positions the torch near the open area to the southeast for and easy laydown fabrication area.

The AC power to feed the DC power supply will be obtained from the existing 12.5 MVA 115 kV/4.16 kV substation. (This is recommended instead of 13.8 kV from the 140 MVA substation, which has been previously considered.) A one-line for the substation can be seen in Figure 7 and the elementary diagram in Figure 8. As can be seen in Figure 8, all four of the breakers are rated 1200A which implies that they could handle 8.6 MVA apiece. The cable leading from breakers B401 and B402, however, is only capable of 5.8 MVA. If we assume the power supply is 85% efficient this only allows 4.9 MW to be delivered to the torch. In able to provide the full power necessary for the torch, one of the 750 MCM cables from B402 will be taken through the wall and into the B401 cubicle. This procedure permits 3 paralleled 750 MCM cables per phase to be taken to the power supply. The existing cables will be cut and spliced in the manhole north of B433. Three new 6" conduits will be taken out of the manhole to the power supply. New 750 MCM cables will be pulled into the conduits, spliced in the manhole, and therefore providing a complete set of three 750 MCM conductors per phase to the power supply.

Environmental considerations are summarized in the Appendix. LLNL would plan to pursue an exemption from the Bay Area Air Quality Management District (BAAQMD) for the torch operation. The exemption is being requested under Regulation 2-1-121.1 which exempts from permitting requirements equipment used for buffing, carving, cutting, drilling, grinding, machining, planing, routing, sanding, sawing, shredding or turning of wood, ceramic, artwork, ceramic precision parts, leather, metals, plastic, rubber, fiberboard, masonry, carbon, or graphite. At present there is a concern about the chromium emission from the exhaust if chromium-copper alloys are used in the electrodes. The assumption for this design is that no processing has to be done on the emissions for the chromium or other material. Therefore, a simple exhaust hood type approach can be used for the emissions. A hood will be built over the refractory vessel

surrounding the graphite load. This hood will have a built-in fan and be connected to an outside stack rising over the roof of the building for dispersion.

Equipment

An assumption was made for this analysis as to the source of the equipment and the responsibilities of the two parties in this testing. Table 2 shows the breakout of the responsibilities for the two parties as presently envisioned. This breakout

	LLNL	PTC
6 MW Plasma Torch		X
Plasma Torch Positioning Equipment		X
Graphite Load with Cooling Stand		X
Refractory Load Vessel		X
Control Panel		X
Power Supply		X
LCW Pump Station		X
Air Compressor		X
Water/Gas Manifold		X
Water/Power Junction Box		X
PTC Supplied Equipment Interconnects		X
Operational Site Preparation (B433)	X	
PTC Equipment Installation	X	
AC Power System Upgrade	X	
Exhaust Equipment Design/Installation	X	
Torch Operation	X	X

Table 2

allows PTC to supply components they traditionally supply for plasma torch installations. Alternatively, LLNL could supply some of the equipment listed as PTC's responsibility. The assessment would have to be modified if this were the case. In the event that LLNL and PTC decide to proceed with the tests, a detailed list of the equipment, etc., supplied by LLNL will be required to prevent any misunderstandings.

Operation

All tests would be conducted under standard Environmental, Safety, and Health (ES&H) rules. The testing, as envisioned, will require LLNL to operate the torch for a few hours, shut it down, and measure electrode erosion. This process will be repeated numerous times until the electrode life can be determined. At this point, the material may be changed and similar operations performed until a

material can be obtained that shows the correct electrode life curve. Some additional life runs would possibly be operated for periods of time from 4 hrs to 24 hrs. The estimated duration for these tests was assumed to be approximately one to two months after the facility is operational; there are likely to be additional operational runs.

Demonstrations for outside visitors would be carried out, perhaps including additional testing. The only stipulation on the visitors is that LLNL would need approximately 1 week prior notification and vital information on foreign nationals. Those from sensitive countries (as defined by DOE) may need up to 2 weeks prior to visitation to allow time to process entrance badges.

The monthly operational costs are worked out assuming two technicians (one electrical and one mechanical), 1/4 of an engineer, and 2 days for the Hazards Control Department per month. The assumed electrical load for these operations is assumed to be 600MWh with no summer peak operation. In other words, the torch would have to be operated during off peak hours during the summer or an additional cost premium would have to be paid.

Costs

The costs for the construction follow the steps outlined in the implementation section above. A preliminary breakout of the costs are listed below; final estimates will be developed if the project proceeds. These estimates are based on detailed scheduling and on manpower and materials costs, and include all LLNL institutional costs and DOE charges for Non-DOE work. The following is the cost breakdown for the facility construction.

	Wage Expense	Procurement Expense
Remove B433 Equipment	63.5	27.7
Store B433 Equipment	4.8	37.2
Site Preparation	4.1	2.8
PTC Equipment Mount	11.1	3.9
PTC Equipment Install	33.0	40.0
Connect Power Supply AC Power	54.4	47.3
Torch Exhaust	<u>60.9</u>	<u>52.4</u>
	608.4	223.4
Subtotal	831.8	
DOE Depreciation 8.9%	<u>74.0</u>	
	905.8	
DOE Added Factor 15.4%	<u>139.5</u>	
Total	\$1045.3K	

Operational costs per month are the following:

	Wage Expense
Mechanical Technician	16.1
Electronic Technician	16.1
Engineer (1/4)	4.9
Hazards Control (2 days)	<u>1.6</u>
	38.6
Electricity (600 MWh)	<u>38.5</u>
	77.1
DOE Depreciation 8.9%	<u>6.9</u>
	83.9
DOE Added Factor 15.4%	<u>12.9</u>
Grand Total	\$96.8K

Schedule

The installation from the beginning of the equipment removal to the first operation will take five months. This time frame assumes manpower leveling to maintain a level work force over the life of this installation. The schedule can be shortened if more people are front end loaded on the job. This could decrease the time to completion to 3.5 months.

The schedule assumes LLNL will receive the air exemption for the operation of the torch. If the exemption is not granted, and an air permit is required or exhaust gases have to be treated, these elements may cause an increase in the amount of months necessary for completion.

Plans

All PTC equipment installed in B433 will remain PTC equipment and all equipment specially built and designed for PTC that is not a part of the building will become PTC property. The equipment can be removed at anytime. PTC will pay for the removal of the equipment; this cost has not been estimated. The system can remain in operation upto one year for the space charge listed in the estimate for setting up the facility. If the operation runs over one year from the start of the project, an additional space charge will have to be paid for an additional year.

Once the facility is set up and the initial demonstration tests are complete, the facility could be available for future uses of the plasma torch technology.

Appendix: Environmental Considerations

The operation of a plasma torch for the purpose of testing and demonstrating the device operational capabilities would produce considerably less environmental impacts than the use for pyrolysis or vitrification. Never-the-less, there are potential impacts which need to be considered to ensure that they are negligible or mitigated.

The present analysis is based on scaling from emission tests² on a similar torch used in a furnace. The tests were done using an EPA Method sampling train as part of the air emissions permitting process.

The results included both gaseous and particulate emissions. The first will be common to torches essentially independent of the use, whereas the particulate emissions result from the use of the torch in the furnace. The results of the test are attached as Table 2-1 from the test report. The CO production will be increased above the earlier tests by the use of a graphite target in the present experiment. In addition, there is a possible chromium emission from erosion of the electrode materials which must be considered.

The maximum nitrogen oxide production was measured to be 992 ppmvd at a collection temperature of 113°F (45° C). The flow of air through the present torch is less than 300 scf/minute (standard cubic feet/minute), resulting in a NO_x production less than 0.3 scf/m = 8.4 liters/minute = 0.015 kg/minute (for NO₂). Thus, in an 8 hour day the maximum NO_x production is 7.2 kg (16 lb/8 hour day).

From experience, the erosion rate of the graphite target is 1 Kg per hour. The primary reaction is expected to be $4\text{C} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 2\text{CO}$, with half the carbon going into CO. The estimated CO emission is thus 1.17 kg/hr = 2.6 lb per hour (20.6 lbs/8 hour day). As a secondary reaction, it is estimated that 30-34% of the CO emission will be converted to CO₂ due to the presence of high temperature and excess oxygen.

Both of these emissions are well within those required for an air permit exemption by the Bay Area Air Quality Control Board (150 lbs/day of any single pollutant) BAAQMD Regulation 2 Permits, Rule 1 General Requirements. If the limits are reduced to 50 lbs/day, CO production may limit operations to 19 hours in the absence of the secondary reaction; with a 30% secondary reduction there is no constraint.

² Entropy Environmentalists, Inc., Stationary Source Sampling Report, Reference No. 6232, [Plasma Energy Corporation, Raleigh, North Carolina], March 30, 1989.

One proposed electrode material uses a copper alloy containing 3-7% chromium. The presence of chromium vapor at high temperatures, together with an oxidizing agent (O_2 from air) will typically produce CrO_3 which is toxic. As the melting point of CrO_3 is $196^\circ C$, the material is easy to trap or condense out onto a region downstream from the torch. It can then easily be put into a basic solution where it can undergo chemical reactions to convert it into a safe compound. If this alloy is used, a trap will be required to meet the emission standards unless further analysis demonstrates that the emissions are below the standard. The cost of such a trap has not been included in the estimates in this report.

Hazardous waste generated consisting of hexavalent chromium, e.g. CrO_3 , are significantly regulated by California state regulations. The Bay Area Air Quality Management District (BAAQMD) trigger level where risk screening is required for chromium (+ 6) is 3.8×10^{-8} lb/ day. The trigger level stated above will require us to submit a permit application for the source. The permit application will determine whether BAAQMD will allow us to emit the contaminant or they will require us to provide some sort of abatement device for the unit. If a permit is required, it will address all emissions, including NO_x and CO.

Alternatively, it is suggested that alloys including chromium not be used.

FIGURE 1
PLASMA TORCH COMPONENTS

PLASMA HEATING
SYSTEM -PHS-
FIGURE No. 2

POWER SUPPLY

AIR COMPRESSOR

PUMP STATION

(C-8) FURNACE GROUND
NOT SHOWN
BY CUSTOMER
NOT SHOWN

FIGURE 3
BY33 EXISTING BUILDING CONFIGURATION

A	1990	25	DEA	MAC	NUMANAN
B	1990	26	DEA	MAC	NUMANAN
C	1990	27	DEA	MAC	NUMANAN
D	1990	28	DEA	MAC	NUMANAN
E	1990	29	DEA	MAC	NUMANAN
F	1990	30	DEA	MAC	NUMANAN
G	1990	31	DEA	MAC	NUMANAN
H	1990	32	DEA	MAC	NUMANAN
I	1990	33	DEA	MAC	NUMANAN
J	1990	34	DEA	MAC	NUMANAN
K	1990	35	DEA	MAC	NUMANAN
L	1990	36	DEA	MAC	NUMANAN
M	1990	37	DEA	MAC	NUMANAN
N	1990	38	DEA	MAC	NUMANAN
O	1990	39	DEA	MAC	NUMANAN
P	1990	40	DEA	MAC	NUMANAN
Q	1990	41	DEA	MAC	NUMANAN
R	1990	42	DEA	MAC	NUMANAN
S	1990	43	DEA	MAC	NUMANAN
T	1990	44	DEA	MAC	NUMANAN
U	1990	45	DEA	MAC	NUMANAN
V	1990	46	DEA	MAC	NUMANAN
W	1990	47	DEA	MAC	NUMANAN
X	1990	48	DEA	MAC	NUMANAN
Y	1990	49	DEA	MAC	NUMANAN
Z	1990	50	DEA	MAC	NUMANAN

FIGURE 4
BY33 EXISTING ISOLATED FOUNDATIONS

BILL OF MATERIAL			MATERIAL
ITEM	PART NAME	QTY	DESCRIPTION

[illegible]

* Note: All Claymont Given As
 Generalized To 66,000.
 Actual Flotation Is 65.7

[illegible]

FIGURE 5

REV	DATE	BY	CHKD	APPD	REVISION
A					SEE OLD PLAN, PAGE 55
B					REVISION
C					REVISION
D					REVISION
E					REVISION
F					REVISION
G					REVISION
H					REVISION
I					REVISION
J					REVISION

PLASMA TORCH EQUIPMENT LAYOUT

ANCHOR BOLT PLAN 1/4\"/>

**Note: All dimensions given are
 referenced to 00.000.
 ACTUAL ELEVATION TO BE SET.*

DETAIL ①

1/4\"/>

DETAIL ②

1/4\"/>

DETAIL ③

1/4\"/>

REVISED	DATE	BY	CHKD	APPD	REVISION

REVISED	DATE	BY	CHKD	APPD	REVISION

REVISED	DATE	BY	CHKD	APPD	REVISION

REVISED	DATE	BY	CHKD	APPD	REVISION

REVISED	DATE	BY	CHKD	APPD	REVISION

FIGURE 6

ELEMENTARY
DIAGRAM

Company: / Location:
 Laramie
 Laramie Regional
 Laboratory
 PLANT ENGINEERING

MFTF-B
 CRYOGENIC
 SUBSTATION
 ELECTRICAL
 INSTALLATION

Project: MFTF-B Cryogenic Substation
 Date: 10/1/88
 Drawn: J. J. [illegible]
 Checked: [illegible]
 Released: [illegible]
 Approved: [illegible]

3
 PLEB-43109D

NOTE

* GROUND SENSOR, CT, ALIAS RELAY
 AND CONTROL WIRING ARE ALSO
 AN INHERENT PART OF SWITCHGEAR
 ASSEMBLY

Figure 8