

## NCSX Work Approval Form (WAF)

**WBS Number: 64**

**WBS Title: Bakeout Systems**

**Job Number: 6401**

**Job Title: Bakeout Systems**

**Job Manager: Mike Kalish**

**Description:**

The WBS element consists of the effort to provide heating and cooling to the vacuum vessel. The system supports high-temperature bakeout of the vessel and control of the vacuum vessel temperature under heat loading from plasma losses and heat losses to surrounding cold structure.

**Schedule:**

See Attached

**Approvals:**

_____	_____
Job Manager	Date
_____	_____
Responsible Line Manager	Date
_____	_____
Project Manager	Date
_____	_____
Engineering Department Head	Date



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TABLE II - Materials and Subcontracts

<b>WBS Number: 64</b>									
<b>WBS Title: Bakeout Systems</b>									
<b>Job Number: 6401</b>									
<b>Job Title: Bakeout Systems</b>									
<b>Job Manager: Mike Kalish</b>									
<b>Materials and Subcontracts (M&amp;S)</b>									<b>Basis of Estimate</b>
<b>M&amp;S in Table I</b>									

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**TABLE III - Fabrication/Assembly Installation**

<b>In-house Fabrication and Assembly and Installation</b>															
<b>Fabrication &amp; Installation in Table I</b>															

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**TABLE IV - Uncertainty of Estimate and Residual Risk Assessment**

**WBS Number: 64**  
**WBS Title: Bakeout Systems**  
**Job Number: 6401**  
**Job Title: Bakeout Systems**  
**Job Manager: Mike Kalish**

**Uncertainty of the Estimate**

	<u>High</u>	<u>Medium</u>	<u>Low</u>	<u>Uncertainty Range (%)</u>	<u>Comments/Other Considerations</u>
Design Maturity			X	-20%/+40%	This is a preconceptual design using a new (to PPPL) type of blower and heater.
Design Complexity		X			Due to the high thermal excursions, difficult permeability requirements and safety considerations, the design is considered medium complexity.

**Note: High/Medium/Low uncertainty assessment from Job Manager. Uncertainty range based on ACEI recommended practice 18R-97 as amended for NCSX.**

**Residual Impacts**

Job	Risk Description	Likelihood of Occurring	Mitigation Plan	Basis of estimate	Cost Impact		Schedule Impact	
					Low	High	Low	High
NONE								

**Notes:**

- [1] Low cost and schedule impacts are considered the minimum (0-percentile) impacts should the event occur. High cost and schedule impacts are considered the maximum (100-percentile) impacts should the event occur
- [2] Cost impacts should be entered as man-hours (by demographic) and M&S direct cost under basis of estimate. Cost impacts should NOT include standing army costs which are separately calculated from the schedule impact. Project control is responsible for quantifying the low and high cost impacts based on the labor hours and M&S identified
- [3] The schedule impacts should be entered as the min and max impacts on the critical path. If there is no critical path impact then the schedule entries should be zero.
- [4] Likelihood of occurrence should be entered consistent with our risk classification methodology, i.e. VL= Very Likely (P>80%), L=Likely (80%>P>40%), U=Unlikely (40%>P>10%), VU=Very Unlikely (P<10%), NC=Non-credible (P<1%)

**NCSX June 2007 ETC  
TABLE V - Basis of Estimate**

**WBS Number: 64  
WBS Title: Bakeout Systems  
Job Number: 6401  
Job Title: Bakeout Systems  
Job Manager: Mike Kalish**

**Estimate Backup**

6401 HEAT TORCH Bakeout System REV3.xls					5/21/2007				
Size	Labor Manhours	Material Cost (\$)	Total Labor (Mhours)	M&S (\$) (in 2002 \$)	Size	Labor Manhours	Material Cost (\$)	Total Labor (Mhours)	M&S (\$) (in 2002 \$)
<b>304 SS</b>					<b>304 SS</b>				
<b>Sch10 with Clevis hangers</b>					<b>VALVES</b>				
Linear Feet	0.150	\$8	0	\$0	3" Backpressure control valve	8	\$8,000	8	\$8,000
1-1/4"	0.176	\$10	0	\$0	2" Balancing Valve	8	\$900	48	\$4,800
1-1/2"	0.193	\$11	0	\$0	16"	16,000	\$900	0	\$0
2"	0.239	\$14	48	\$2,700	3" Ceramic Breaks	23	6,000	144	\$28,800
2-1/2"	0.314	\$17	0	\$0	3" Belows	23	6,000	144	\$3,240
3"	0.348	\$21	174	\$10,250	<b>Gas Blower</b>	32	\$4,000	32	\$4,000
<b>Sch 5 and 10 NO JOINTS</b>					<b>Instll Hr</b>				
1"	1,000	0	0	\$0	Instll Instru	16,000	\$200	0	\$0
<b>ELBOWS</b>					<b>Instll Pwr</b>				
Quantity					Instll Tank	96,000	\$5,000	0	\$0
1-1/2"	1,230	\$14	0	\$0	Piping Support Towers	150,000	\$3,000	640	\$12,000
2"	1,450	\$19	44	\$555	<b>Totals</b>			2470	\$112,071
2-1/2"	2,000	\$40	0	\$0	<b>Subtotal (2002\$)</b>				
3"	2,670	\$48	27	\$415	<b>Escalation from 2002\$ to 2007\$ for 304SS</b>			1.40	
4"	4,000	\$78	0	\$0	<b>Approximate Cost of M&amp;S in 2007\$</b>				<b>\$157,196</b>
<b>TEES</b>									
Quantity									
2"	2,290	\$37	23	\$370					
1-1/2"	3,200	\$116	0	\$0					
3"	4,000	\$81	20	\$405					
4"	8,000	\$101	0	\$0					
<b>Addns</b>									
Elevated Installation	72,735		73						
amic Breaks (Fab and Install)	8,000	\$2,000	48	\$12,000					
Insulation	48,490	\$1,476	48	\$1,476					

# NCSX June 2007 ETC TABLE V - Basis of Estimate

**Calculations**

THE FOLLOWING CALCULATIONS DETERMINE THE MASS FLOW RATE THROUGH THE INTERNAL PFC TUBING GIVEN THE PRESSURE DROP AND AIR PROPERTIES  
For air, once through

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Calculate the pressure drop through the PFC tubing. Adjust  $k$  and  $\mu_h$  for Temperature

$$k := .015 \frac{\text{BTU}}{\text{hr} \cdot \text{ft} \cdot \text{R}} \quad T_{\text{inlet}} = 273 + 20 \quad C_p := .241 \frac{\text{BTU}}{(\text{lb} \cdot \text{R})} \quad \mu_h := 39.16 \cdot 10^{-8} \frac{\text{lb} \cdot \text{sec}}{\text{ft}^2} \quad \mu_h := 0.0187 \text{ centipoise}$$

viscosity from CRC handbook or (Marks pg 3-36) changes with temp. but not pressure

$$\rho_h \text{ at std} := 0.76 \frac{\text{lb}}{\text{ft}^3}$$

$$p = 1.5 \text{ psi} \quad P_{\text{avg}} := P_{\text{sys}} - \frac{\Delta p}{2} \quad P_{\text{avg}} = 14.25 \quad T_{\text{avg, sys}} := \left( \frac{T_{\text{inlet}} + T_{\text{outlet}}}{2} + T_{\text{outlet}} + 273 \right)$$

$$\rho_h := \rho_h \text{ at std} \left( \frac{P_{\text{avg}} + 14.7}{14.7} \right) \left( \frac{293}{T_{\text{avg, sys}}} \right) \quad \rho_h = 0.098 \frac{\text{lb}}{\text{ft}^3} \quad T_{\text{inlet}} = 200.0 \quad T_{\text{outlet}} = 150.0$$

$\epsilon_{\text{cui}} := 10 \cdot 10^{-6} \text{ ft}$  for drawn copper tube     $\epsilon_{\text{pipe}} := 150 \cdot 10^{-6} \text{ ft}$  for steel pipe (ref. 3-55 Marks)

$d_p = 0.257 \text{ in}$      $d_p = 0.653 \text{ cm}$  inner diameter of cooling passage for a round cross-section

$L = 216.536 \text{ in}$  hydraulic length of opening under evaluation

$$\mu := \mu_h \quad \rho := \rho_h \quad \epsilon := \epsilon_{\text{pipe}} \quad \text{Input Values} \quad v := \frac{v}{\rho} \quad P_{\text{avg}} = 14.25$$

Calculate the Reynolds # using the velocity and diameter. Use the hydraulic diameter if it is not a round cross-section

For a round pipe     $d_p = 0.257 \text{ in}$      $\text{Area}_p := \left( \frac{d_p}{2} \right)^2 \pi$

$D := d_p$      $A := \text{Area}_p$     Input Hydraulic Diameter and Area     $A = 0.052 \text{ in}^2$

Now calculate the flow through a pipe when only the head loss through the pipe and pipe size is known

$$D = 0.257 \text{ in} \quad \rho = 5.665 \times 10^{-5} \frac{\text{lb}}{\text{in}^3} \quad p = 1.5 \text{ psi} \quad \epsilon = 1.5 \times 10^{-4} \text{ ft} \quad \mu = 3.916 \times 10^{-7} \frac{\text{lb} \cdot \text{sec}}{\text{ft}^2}$$

$$h_f := \frac{p}{\rho \cdot g}$$

$$f := -2 \cdot \log \left[ \frac{\epsilon}{3.7D} + \frac{2.51}{\rho \cdot D} \left( \frac{\mu}{2g \cdot h_f \cdot D} \right)^{0.5} \right]^2$$

This equation solves for f (friction factor) when the flow rate is unknown but the head loss is known, check for laminar flow

$$f = 0.04 \quad \frac{\epsilon}{D} = 7.004 \times 10^{-3}$$

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Now solve for the Reynolds # in terms of the friction factor.

$$Re_1 := \frac{9.287}{\sqrt{f}} \left( 3.7 \cdot \exp \left( \frac{-1.15129}{\sqrt{f}} \right) - \frac{\epsilon}{D} \right)^{-1} \quad Re_1 = 1.086 \times 10^4 \quad \text{for turbulent flow}$$

$$Re_1 := \frac{64}{f} \quad Re_1 = 1.619 \times 10^3 \quad \text{for laminar flow}$$

Check that Re is turbulent if not use  $Re=64/f$

Reference pg. 3-55 Marks to determine if flow is laminar or turbulent. Generally turbulence begins at  $Re > 2000$

$$Re := \text{if}(Re_1 < 2000, Re_1, Re_2) \quad Re = 1.086 \times 10^4 \quad f = 0.04$$

$v := \frac{\mu \cdot Re}{D \cdot \rho} \quad v = 65.295 \frac{\text{ft}}{\text{sec}}$  The velocity of the fluid

$Q := v \cdot A \quad Q = 1.411 \frac{\text{ft}^3}{\text{min}} \quad mf := Q \cdot \rho \quad mf = 2.303 \times 10^{-3} \frac{\text{lb}}{\text{sec}} \quad mf = 1.044 \frac{\text{gm}}{\text{sec}}$

$H_f := \frac{v^2}{2g} \quad H_f = 66.257 \text{ ft} \quad H_f \cdot \rho \cdot g = 0.045 \text{ psi} \quad A = 0.052 \text{ in}^2$

To find  $f$  for turbulent flow calculate the relative roughness,  $\epsilon/d$ , and use along with the  $Re$  # to look up  $f$  on the graph (pg. 3-55 Marks or pg. A-24 of the Crane tech. manual)

$$mf \cdot N = 1.592 \times 10^3 \frac{\text{lb}}{\text{hr}} \quad d_{\text{allow}} = 50 \text{ K}$$

$$P_{\text{cool}} := mf \cdot C_p \cdot d_{\text{allow}} \quad P_{\text{cool}} \cdot N = 10.117 \text{ kW} \quad mf = 1.044 \times 10^{-3} \frac{\text{kg}}{\text{sec}}$$

## NCSX June 2007 ETC TABLE V - Basis of Estimate

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Now solve for the Reynolds # in terms of the friction factor.

$$Re_i := \frac{0.287}{\sqrt{f}} \left( 3.7 \exp\left(\frac{-1.15129}{\sqrt{f}}\right) - \frac{6}{D} \right)^{-1} \quad Re_i = 1.086 \times 10^6 \quad \text{for turbulent flow}$$

$$Re_i := \frac{64}{f} \quad Re_i = 1.619 \times 10^3 \quad \text{for laminar flow}$$

Check that Re is turbulent if not use Re=64f

Reference pg. 3-65 Marks to determine if flow is laminar or turbulent. Generally turbulence begins at Re=2000

$$Re := \text{if}(Re_i < 2000, Re_i, Re_i) \quad Re = 1.086 \times 10^6 \quad f = 0.04$$

The velocity of the fluid

$$v := \frac{u}{D \rho} \quad v = 65.296 \frac{\text{ft}}{\text{sec}}$$

$$Q := v A \quad Q = 1.411 \frac{\text{ft}^3}{\text{min}} \quad mf := Q \rho \quad mf = 2.303 \times 10^{-3} \frac{\text{lb}}{\text{sec}} \quad mf = 1.044 \frac{\text{g}}{\text{sec}}$$

$$H_f := \frac{v^2}{2g} \quad H_f = 66.257 \text{ ft} \quad H_f \rho g = 0.045 \text{ psi} \quad A = 0.052 \text{ in}^2$$

To find  $f$  for turbulent flow calculate the relative roughness, etc, and use along with the Re # to look up  $f$  on the graph (pg. 3-65 Marks or pg. A-24 of the Crane tech. manual)

$$mf \cdot N = 1.592 \times 10^3 \frac{\text{lb}}{\text{hr}} \quad \Delta T_{\text{allow}} = 50 \text{ K}$$

$$P_{\text{cool}} := mf \cdot c_p \cdot \Delta T_{\text{allow}} \quad P_{\text{cool}} = 10.117 \text{ kW} \quad mf = 1.044 \times 10^{-3} \frac{\text{kg}}{\text{sec}}$$

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**INPUTS**

$N = 96.2$  number parallel paths

$T_{\text{surface}} = 150$   $T_{\text{inlet}} = 200$  in deg C

$T_{\text{lower\_in}} = 20$   $T_{\text{outlet}} = T_{\text{surface}} + 0004$   $T_{\text{outlet}} = 150$

$P_{\text{sys}} = 15$  psi avg pressure in NCSX

$\rho_H = 0.098 \frac{\text{lb}}{\text{ft}^3}$   $\rho_H = 1.568 \frac{\text{kg}}{\text{m}^3}$   $T_{\text{inlet}} \frac{9}{5} + 32 = 392$   $T_{\text{outlet}} \frac{9}{5} + 32 = 302.001$

$\Delta T_{\text{allow}} = (T_{\text{inlet}} - T_{\text{outlet}}) \text{ K}$   $\Delta T_{\text{allow}} = 89.999 \text{ R}$   $\Delta T_{\text{allow}} = 50 \text{ K}$  Temp. drop of helium across vessel

$L = 5.5\text{-m}$  Total length of tubing

$d_p = (2.13 - 2.028) \text{ in}$  Diameter of hole in tubing  $d_p = 0.257 \text{ m}$   $d_p = 0.653 \text{ cm}$

$p = 1.5 \text{ psi}$  dp across tubes

**OUTPUTS**

$v = 65 \frac{\text{ft}}{\text{sec}}$  Velocity of Helium  $P_{\text{avg}} = 14$  psi  $v = 19.902 \frac{\text{m}}{\text{sec}}$

$Q \cdot N = 271 \frac{\text{ft}^3}{\text{min}}$  Volume flowrate of helium through vessel  $Q_{\text{total\_blower}} = 349 \frac{\text{ft}^3}{\text{min}}$  Flow at inlet to Blower

$Q \rho = N = 1.592 \times 10^3 \frac{\text{lb}}{\text{hr}}$  Mass Flow  $\rho = 0.098 \text{ lb ft}^{-3}$

$P_{\text{conv}} = 10 \text{ kW}$  From  $h \Delta T$  Convection heat transfer must equal energy balance

$P_{\text{cool}} = 10 \text{ kW}$  From  $m c_p \Delta T$

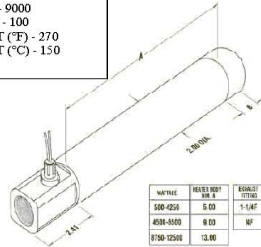
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**NCSX June 2007 ETC**  
**TABLE V - Basis of Estimate**

**Heat Torch Data**

Watts - 9000  
 SCFM - 100  
 Delta T (°F) - 270  
 Delta T (°C) - 150



WATTS	MIN. AIR FLOW (SCFM)	MIN. AIR FLOW (CFM)	OR
500-450	0.03	1-1/4"	1.10
450-900	0.03	1/2"	0.10
900-1250	12.00		

**Specifications**

Max. wattage: 12500  
 Max. exhaust air temp: 1300°F  
 Max. inlet air temp: 250°F  
 Max. SCFM: 100  
 Pressure rating: 120 PSIG  
 Horizontal mounting  
 Leads: 12 gauge, 12' long

**Construction**

Heater body: stainless steel  
 Inlet fitting: nickel plated steel  
 Exhaust fitting: stainless steel

Calculate the wattage, flow rate or temperature requirement as follows:

$$\text{Watts} = \text{SCFM} \times \Delta T \times 3$$

SCFM = airflow in standard cubic feet per minute

$\Delta T$  = temperature rise in degrees F from the inlet to the exhaust

Wattage	Minimum SCFM required	50W-450W Airflow (SCFM)	450W-900W Pressure Drop (PSIG)	900W-1250W Pressure Drop (PSIG)	1250W-1500W Pressure Drop (PSIG)
1000	9.6	10	26	72	1.1
4000	9.6	20	75	1.5	2.3
6000	14.8	30	1.7	3.4	5.1
7000	17.0	40	3.0	9.0	9.0
8000	19.3	50	4.7	9.4	14
9000	21.4	60	6.6	14	20
10000	23.5	70	9.2	16	28
10000	23.5	80	12	24	38
11000	25.5	90	15	30	45
12500	28.4	100	19	38	57