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:

Michael Kalish
Digitally signed by Michael Kalish
DN: cn=Michael Kalish, c=US, o=PPPL, ou=Engineering, email=mkalish@pppl.gov
Date: 2007.07.31 09:10:00 -04'00'

Job Manager — Date

Lawrence E. Dudek
Digitally signed by Lawrence E. Dudek
DN: cn=Lawrence E. Dudek, c=US
Date: 2007.07.31 09:30:43 -04'00'

Responsible Line Manager — Date

James L Anderson
Digitally signed by James L Anderson
DN: cn=James L Anderson, c=US, o=PPPL, ou=NCSX, email=jlanders@pppl.gov
Reason: I am approving this document
Date: 2007.07.31 12:15:24 -04'00'

Project Manager — Date

Mike Williams
Digitally signed by Mike Williams
DN: cn=Mike Williams, o=PPPL, ou=Engineering, email=williams@pppl.gov, c=US
Date: 2007.07.31 12:28:01 -04'00'

Engineering Department Head — Date

NCSX June 2007 ETC
TABLE I - DESIGN LABOR

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

	FY07$K					HOURS												
	$1	$1,000	$1,716	$1,716	$1,716	168.7	168.7	156.5	128.59	108.44	78.33	180.79	116.7	168.88	138.6	138.6	78.33	
TASK DESCRIPTION	41MS	48MS	37STK	35TRVL	31OT	ORNLEM	ORNLDSN	EMEM	EMSM	EMSB	EMTB	EAEM	EASB	EEEM	EESM	EESB	EETB	Basis of Estimae
Design																		
Requirements definition								80										Engineering judgement based on NSTX experience.
Preliminary Design & Review								160					120					Engineering judgement based on NSTX experience.
Final Design & Review								160					120					Engineering judgement based on NSTX experience.
EA or ORNL VV Analysis to confirm												160						Engineering judgement based on NSTX experience.
ACC Review								40			40							
Procurement & Fabrication/Installatio																		
Procurement lead time and award																		
Piping and Equipment (See Piping Estimate T	$157,185										1830							See Material Take Offs in Table V. labor from Means
480 VAC Power Service	$5,000										80							Based on Means
Local Controls	$3,000										80							Based on Means
PTP Testing								40			120							
TOTALS	**$165,185**	**$0**	**$0**	**$0**	**$0**	**0**	**0**	**480**	**0**	**0**	**2150**	**160**	**240**	**0**	**0**	**0**	**0**	
31																		$0
				TOTA	0	0	0	0	0	0	0	0	0	0	0	0	0	0 0 0 0 0 0 $0
																		$0

Notes: Notes:

1. Existing PPPL Air Compressor is not acceptable, only 22 CFM available at 100 psi. Estimate is based on using a Gast Regenerative Blower
2. This estimate is based on a Gast blower operating at the conditions shown in "Calc Summary" Tab
3. Estimate assumes once through air system
4. Estimate assumes 3" 304 SS pipe will be adequate (may require changes by permeability issues)
5. Estimate assumes 150 C VV Bakeout
6. Estimate assumes no VV cooling is required
7. Sizing based on approx. 7 kw heat load
8. Estimate assumes no instrumentation
9. Rev 1 added Piping Support Towers
10. Rev 2 Added Ceramic Breaks and Bellows

TABLE II - Materials and Subcontracts

WBS Number: 64								
WBS Title: Bakeout Systems								
Job Number: 6401								
Job Title: Bakeout Systems								
Job Manager: Mike Kalish								
Materials and Subcontracts (M&S)								**Basis of Estimate**
M&S in Table I								

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TABLE III - Fabrication/Assembly Installation

In-house Fabrication and Assembly and Installation
Fabrication & Installation in Table I

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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

	High	Medium	Low	Uncertainty Range (%)	Comments/Other Considerations
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 AACEI recommended practice 18R-97 as amended for NCSX.

Residual Impacts

Job	Risk Description	Likelihood of Occurring	Mitigation Plan	Basis of estimate	Cost Impact Low	Cost Impact High	Schedule Impact Low	Schedule Impact 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 reponsible 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=Unlikley (40%>P>10%), VU=Very Unlikely (P<10%), NC=Non-credible (P<1%)

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Estimate Backup

6401 HEAT TORCH Bakeout System REV3.xls 5/21/2007

Size		*Labor Manhours*	*Material Cost ($)*	*Total Labor (Mhours)*	*M&S ($) (in 2002 $)*
304 SS					
Sch10 with Clevis hangers	Linear Feet				
1"		0.160	$8	0	$0
1-1/4"		0.176	$10	0	$0
1-1/2"		0.193	$11	0	$0
2"	200	0.239	$14	48	$2,700
2-1/2"		0.314	$17	0	$0
3"	500	0.348	$21	174	$10,250
Sch 5 and 10	NO. JOINTS				
1"		1.000		0	$0
ELBOWS	Quantity				
1-1/2"		1.230	$14	0	$0
2"	30	1.450	$19	44	$555
2-1/2"		2.000	$40	0	$0
3"	10	2.670	$48	27	$475
4"		4.000	$78	0	$0
TEES	Quantity				
2"	10	2.290	$37	23	$370
1-1/2"		3.200	$116	0	$0
3"	5	4.000	$81	20	$405
4"		8.000	$101	0	$0
Adders					
Elevated Installation	15%	72.735		73	
amic Breaks (Fab and Install)	6	8.000	$2,000	48	$12,000
Insulation	10%	48.490	$1,476	48	$1,476

Size		*Labor Manhours*	*Material Cost ($)*	*Total Labor (Mhours)*	*M&S ($) (in 2002 $)*
304 SS					
VALVES					
3" Backpressure control valve	1	8.000	$8,000	8	$8,000
2" Ballancing Valvs	6	8.000	$800	48	$4,800
16"		16.000	$800	0	$0
3" Ceramic Breaks	24	6.000	$1,200	144	$28,800
3" Bellows	24	6.000	$135	144	$3,240
Gast Blower	1	32.000	**$4,000**	32	$4,000
Instll Htr	1	40.000	$6,000	40	$6,000
Install Instru		16.000	$200	0	$0
Install Pwr	1	120.000	$5,000	120	$5,000
Install Tank		96.000	$5,000	0	$0
Piping Support Towers	4	160.000	$3,000	640	$12,000
		Totals			
Subtotal (2002$)				2470	$112,071
Escalation from 2002$ to 2007$ for 304SS					1.40
Approximate Cost of M&S in 2007$					**$157,186**

6401 HEAT TORCH Bakeout System REV3.xls Piping Estimate page 1 of 1 5/21/2007 1:37 PM

NCSX June 2007 ETC
TABLE V - Basis of Estimate

Calculations

Michael Kalish 7/2/2004

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

Calculate the pressure drop through the PFC tubing. Adjust k and μ_h for Temperature

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

viscosity from CRC handbook or (Marks pg 3-36) changes with temp. but not pressure $\quad \mu_h = 39.2 \, 10^{-8} \cdot \frac{lbf \cdot sec}{ft^2}$ $\quad \mu_h = 0.0187 \, centipoise$

$\rho_{h\_at\_std} := .076 \cdot \frac{lb}{ft^3}$

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

$\rho_h := \rho_{h\_at\_std} \cdot \left(\frac{P_{avg} + 14.7}{14.7} \right) \left(\frac{293}{T_{avg\_sys}} \right)$ $\quad \rho_h = 0.098 \frac{lb}{ft^3}$ $\quad T_{avg\_sys} - 273 = 175$ $\quad T_{inlet} = 200.0$ $\quad T_{outlet} = 150.0$

$\epsilon_{cu} := 10 \cdot 10^{-6} \cdot ft$ for drawn copper tube $\quad \epsilon_{pipe} := 150 \cdot 10^{-6} \cdot ft$ for steel pipe (ref. 3-56 Marks)

$d_p = 0.257 \, in$ $\quad d_p = 0.653 \, cm$ inner diameter of cooling passage for a round cross-section

$L = 216.535 \, in$ hydraulic length of opening under evaluation $\quad \rho_h = 1.568 \times 10^{-3} \frac{gm}{cm^3}$

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

Calculate the Reynolds # using the velocity and diameter. Use the hydraulic diameter if it is not a round cross-section $\quad T_{avg\_sys} - 273 = 175$

For a round pipe $\quad d_p = 0.257 \, in$ $\quad Area_p := \left(\frac{d_p}{2} \right)^2 \cdot \pi$

$D := d_p$ $\quad A := Area_p$ Input Hydraulic Diameter and Area $\quad A = 0.052 \, in^2$

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

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

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

$$f := \left[-2 \cdot \log \left[\frac{\frac{\epsilon}{D}}{3.7} + \frac{2.51}{\rho \cdot \frac{D}{\mu} \cdot \left(2 \cdot g \cdot h_f \cdot \frac{D}{L} \right)^{.5}} \right] \right]^{-2}$$

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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Michael Kalish 7/2/2004

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

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

$Re_l := \frac{64}{f}$ $\quad Re_l = 1.619 \times 10^3$ 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 turbulance begins at Re>2000

$Re := if(Re_t < 2000, Re_l, Re_t)$ $\quad Re = 1.086 \times 10^4$ $\quad f = 0.04$

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

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

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

To find f.t for turbulent flow calculate the relative roughness, e/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)

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

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

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NCSX June 2007 ETC
TABLE V - Basis of Estimate

Michael Kalish 7/2/2004

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

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

$Re_l := \frac{64}{f}$ $Re_l = 1.619 \times 10^3$ 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 turbulance begins at Re>2000

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

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

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

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

To find f.t for turbulent flow calculate the relative roughness, e/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)

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Michael Kalish 7/2/2004

INPUTS $N \equiv 96 \cdot 2$ number parrallel paths

$T_{surface} \equiv 150$ $T_{inlet} \equiv 200$ In deg C

$T_{blower\_in} \equiv 20$ $T_{outlet} \equiv T_{surface} + .0004$ $T_{outlet} = 150$

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

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

$dt_{allow} \equiv (T_{inlet} - T_{outlet}) \cdot K$ $dt_{allow} = 89.999\, R$ $dt_{allow} = 50\, K$ Temp. drop of helium across vessel

$L \equiv 5.5 \cdot m$ Total length of tubing

$d_p \equiv (.313 - 2 \cdot .028) \cdot in$ Diameter of hole in tubing $d_p = 0.257\, in$ $d_p = 0.653\, cm$

$p \equiv 1.5 \cdot psi$ dp across tubes

OUTPUTS

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

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

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

$P_{conv} \cdot N = 10\, kW$ From hAdt Convection heat transfer must equal energy balance

$P_{cool} \cdot N = 10\, kW$ From $mc_p dt$

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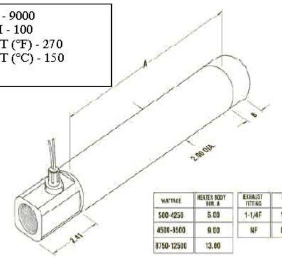
NCSX June 2007 ETC
TABLE V - Basis of Estimate

Heat Torch Data

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



WATTAGE	HEATER BODY DIM. A	EXHAUST FITTING	DIM. B
500-4250	5.00	1-1/4F	1.13
4500-8500	9.00	NF	0.10
8750-12500	13.00		

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:

Watts = SCFM x $\Delta T/3$

SCFM = airflow in standard cubic feet per minute

ΔT = temperature rise in degrees F from the inlet to the exhaust

Wattage	Minimum SCFM required
1000	9.6
4000	9.6
5000	12.4
6000	14.8
7000	17.0
8000	19.3
9000	21.4
10000	23.5
11000	25.5
12500	28.4

Airflow (SCFM)	500W-4250W Pressure Drop (PSIG)	4500W-8500W Pressure Drop (PSIG)	8750W-12500W Pressure Drop (PSIG)
10	.36	.72	1.1
20	.75	1.5	2.3
30	1.7	3.4	5.1
40	3.0	6.0	9.0
50	4.7	9.4	14
60	6.8	14	20
70	9.2	18	28
80	12	24	36
90	15	30	45
100	19	38	57

Activity ID	MILE-stones (level 2 & 3)	Activity Description	Duration (work days	Baseline Start	Baseline Finish	Shifts	Total Float	% cmplt	Proposed Budgeted
64 - PFC/VV Heating & Cooling (Bakeout)									
Job: 6401 - PFC/VV Htng/Cooling(bakeout)- KALISH									
6401-000		Bakeout Sys- Requirements Definition	40	06APR09*	01JUN09		93		15,296.80
6401-001		Bakeout Sys-Preliminary Design	40	02JUN09*	28JUL09		93		43,874.32
6401-002		Bakeout Sys-PDR	1	29JUL09*	29JUL09		93		1,529.68
6401-004		Bakeout Sys- EA Analysis	30	30JUL09	10SEP09		93		30,593.60
6401-005		Bakeout Sys-Final Design	40	11SEP09*	05NOV09		93		44,844.12
6401-009		Bakeout Sys-FDR	1	06NOV09*	06NOV09		93		1,581.68
6401-010		Bakeout Sys-Procure Piping & Equipt	65	09NOV09*	19FEB10		93		236,552.08
6401-013		Assemble & Install	65	22FEB10*	21MAY10		93		169,667.40
6401-017		Bakeout Sys- ACC Review	10	24MAY10*	07JUN10		93		11,318.80
6401-020		Bakeout Sys-PTP Testing	10	08JUN10*	21JUN10		93		18,139.60
Subtotal			302	06APR09	21JUN10		93		573,398.08