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Status of Efforts to Limit Mu2e Activated Air Emissions (and Contamination)

Mike Andrews, Emil Huedem, James Hylen, Kurt Krempetz, Tony Leveling, Ryan Schultz
(and Rick Coleman, Ang Lee, Andy Stefanik and Kamran Vaziri)

George Ginther
Remote Handling Status Update
20 July 2015

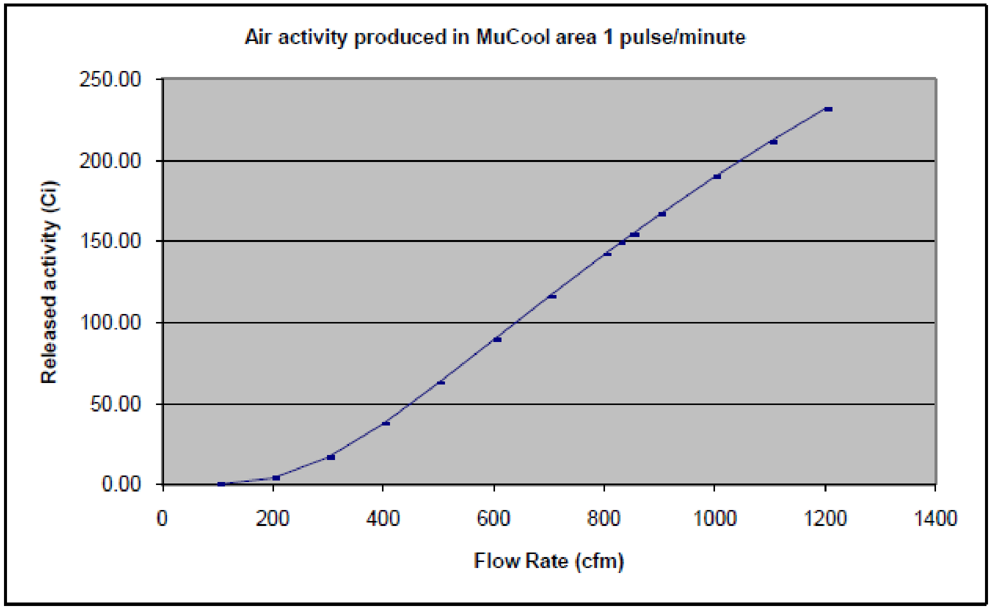
Limiting Release of Airborne Radioactivity

- The most serious potential sources of radioactive particulates are likely to be the proton beam absorber, the primary target, and activation of the air between the PS and the proton beam absorber
  - Anticipate that dispersion of particulates from the proton absorber will be suppressed by design and surface preparation of the proton absorber as well as operating procedures
    - Airflow around absorber and into albedo trap should reduce air velocity and minimize transport of entrained particulates beyond the albedo trap
    - Plan to divert airflow from proton absorber to the remote handling area during access to the PS area
  - Anticipate that spread of particulates from the primary proton target will be suppressed via contamination containment measures to be integrated into the target remote handling system
    - Potential concern about ^{7}Be (see Tony's presentation)
  - To minimize risk of migration of activated particulates:
    - The PS area should be maintained at neutral or negative pressure differential relative to surrounding areas
    - Potential for particulate contamination beyond PS area minimized by directing airflow from that area through HEPA filter (with prefiltering) during beam operations
    - Either the remote handling room shield door or the doors on the east side of the remote handling room should be closed whenever the hatch to the east of the remote handling room is open (after beam operations)
- Basic plan to control radioactive gas emission rates is to design air flow so that the activated air will be directed up the M4 beamline and vented via a stack in the AP-30 during beam operations with a sufficiently long transit time to satisfy the stringent safety requirements
  - After an appropriate cooldown time following beam operations, it is not currently anticipated that any special constraints on air flow will be required when the beam is not operating with possible exception of access to the PS area

Kamran Vaziri
Docdb 1553

Air Activation Levels
Target, window and absorber

Target Hall



FlowRate(cfm)	Released (Ci/yr)
100	0.40
200	4
300	17
400	38
500	63
600	89
700	116
800	142
827	149
850	154
900	166
1000	190
1100	211
1200	232
1300	251

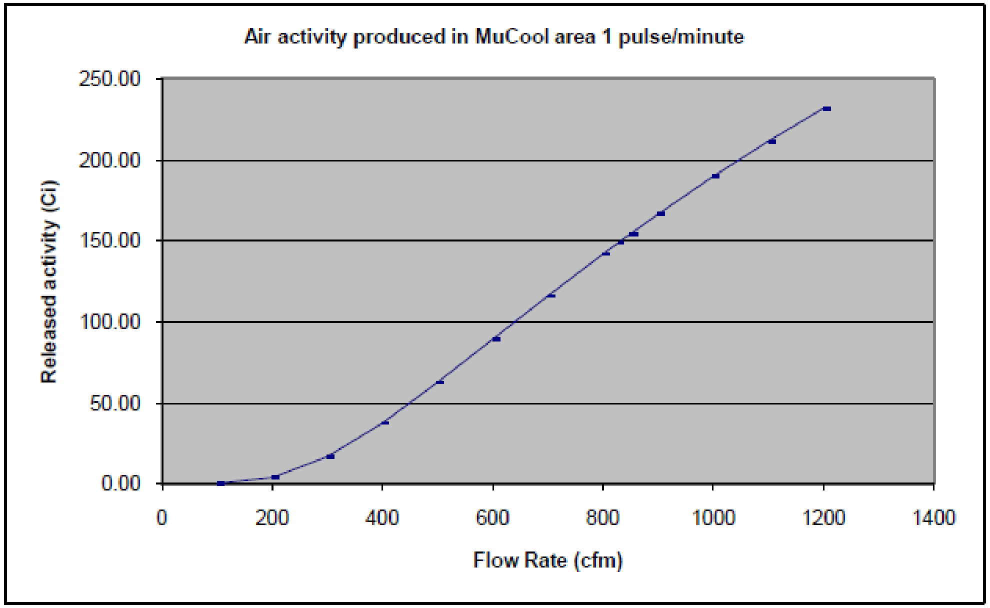
- 25kW beam analysis (May 2011), but with earlier beam absorber area design
- Our understanding is that the site limit is approximately 300 Ci/year
- So the anticipated limit for Mu2e emissions is 100Ci/year
- Result appeared to indicate that for an 8kW beam an airflow rate of more than 1300 CFM might result in acceptable emission levels

Kamran Vaziri
Docdb 1553

Air Activation Levels
Target, window and absorber

25 kW

Target Hall



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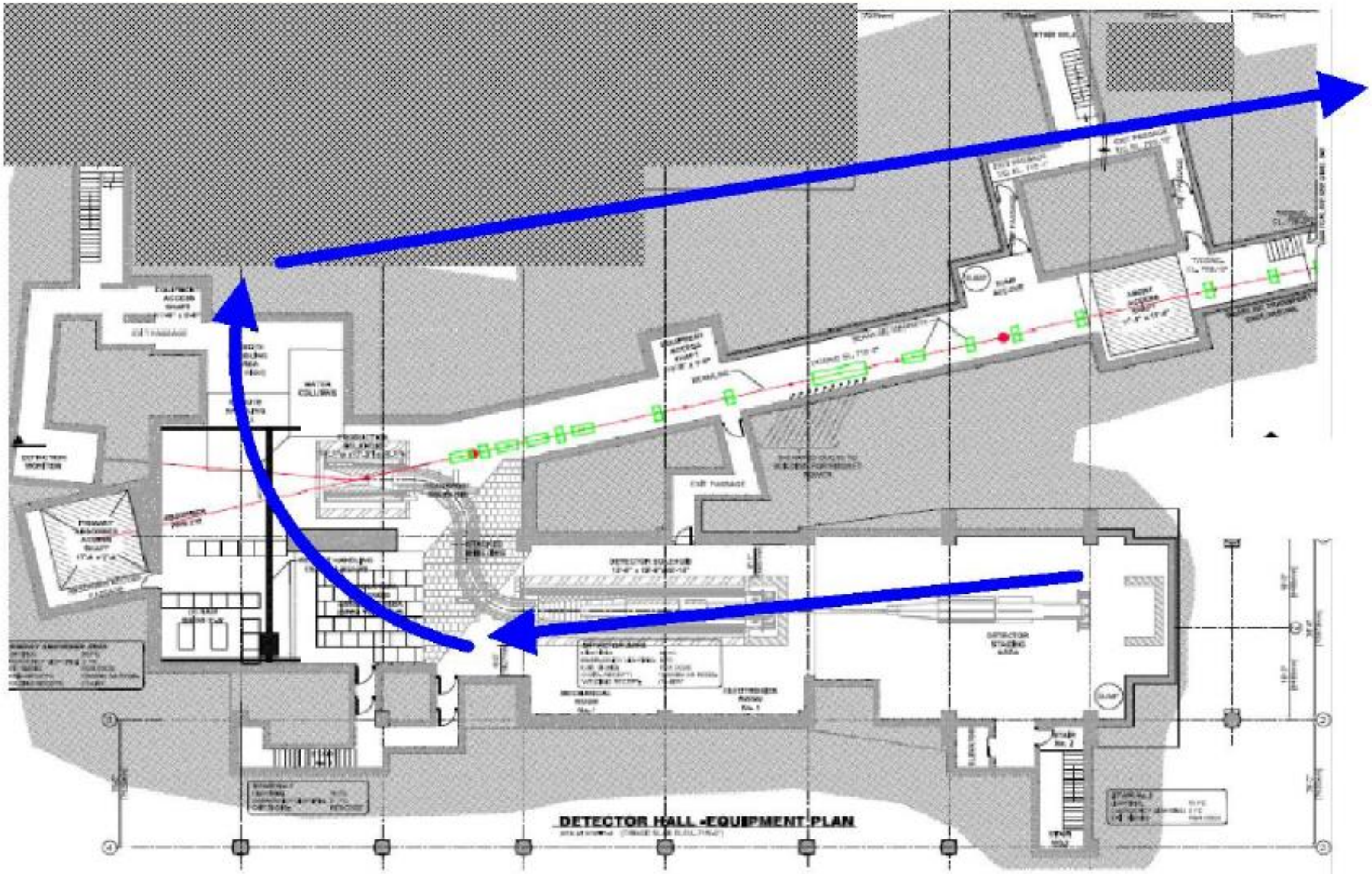
5/4/11 Independent Design Review of the Mu2e Project for CD-1 28

Target Hall Ideal Air Flow

Docdb 1553



5/4/11 Independent Design Review of the Mu2e Project for CD-1 29

Overview of Air Handling Related Activities Since March

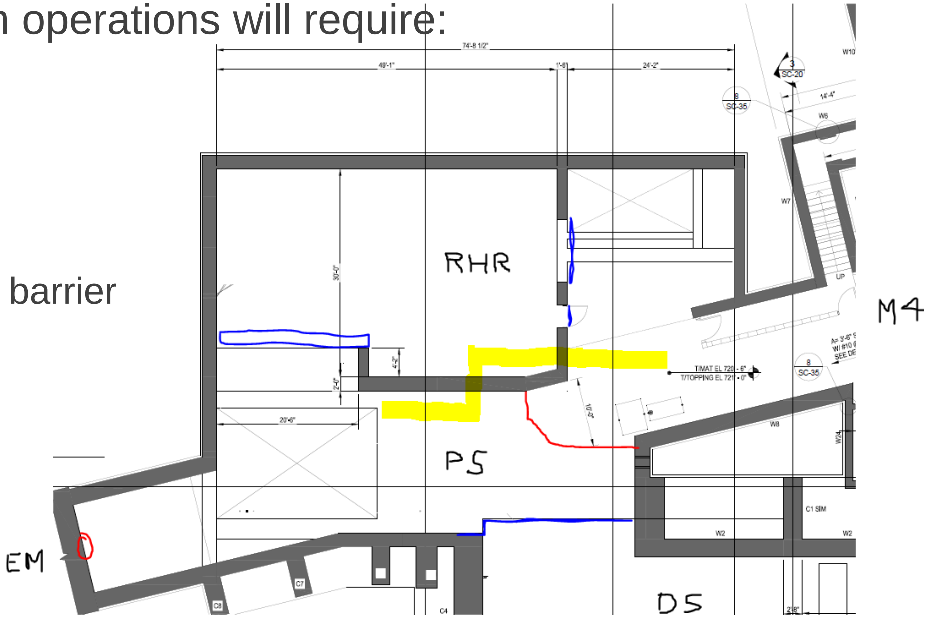
- It seemed plausible that airflows ~1400 CFM along the M4 beamline should result in acceptable emission levels
  - The initial emphasis was therefore on understanding configurations, considering air barriers, evaluating pressure differentials and impacts of penetrations
- Once a “solution” was generated that provided sufficient pressure differentials to ensure airflows in the desired directions, Tony performed an initial analysis of the radioactive air emissions
  - Discussions with Kamran called into question the assumption that airflows ~1400CFM would result in acceptable emission levels
    - Asked Kamran to provide an air activation assessment based upon inputs from Tony and Emil
    - Began exploration of modifications to airflow requirements into the proton absorber

Controlling Activated Air

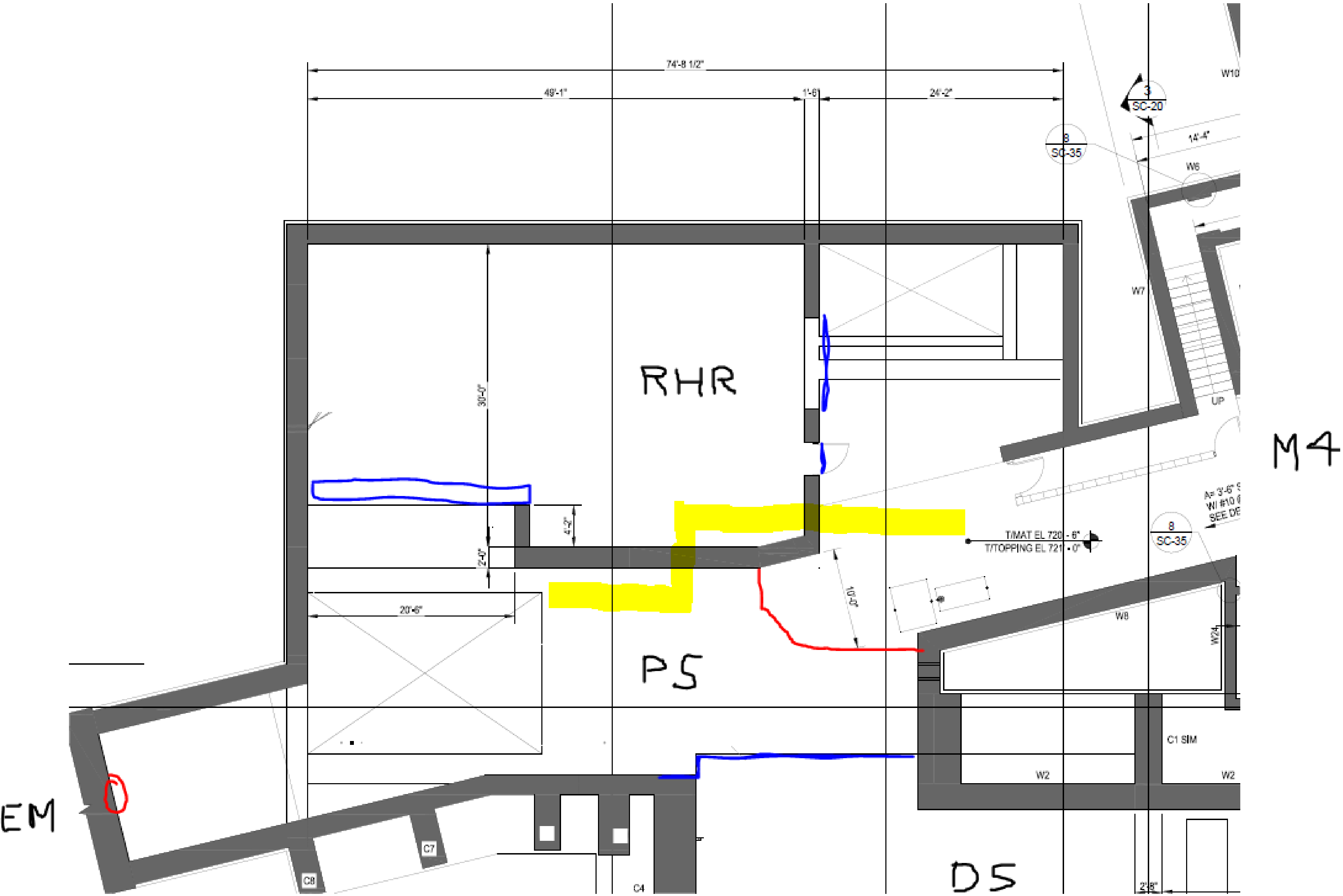
- Generate pressure differential between PS area and surrounding areas to control direction of air flow
  - Experience indicates that a 0.02” water pressure differential will not provide sufficient margin
    - Based upon ACNET logged data at pbar and in NUMI
  - There is reason to believe that 0.1” water pressure differential should be adequate
    - LBNF is planning to use 0.1” as a goal
  - 0.05” water pressure differential is viewed as the absolute minimum design differential pressure for reliable performance
    - to ensure the desired airflow direction is maintained even during changing weather conditions
  - Adopt 0.1” water pressure differential as the preferred design parameter

Controlling Activated Air

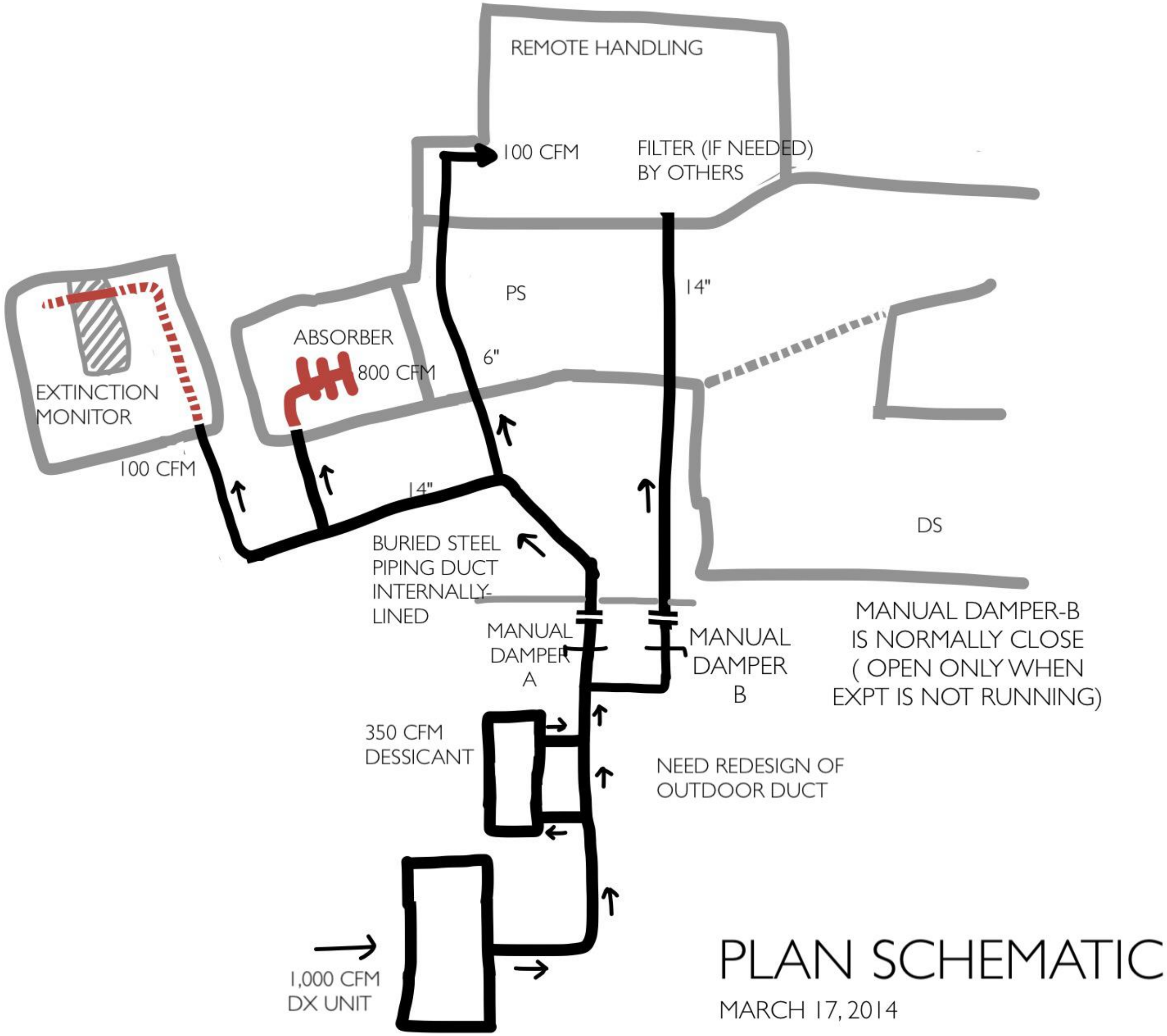
- Propose to arrange barriers and air handling so that the PS area is at negative pressure relative to surrounding areas during beam operations so that activated air will flow up the M4 beamline to AP-30
  - Note that some of these areas will have cryogens and gas supplies, so Oxygen Deficiency Hazards must also be considered
- To achieve this negative pressure during beam operations will require:
  - PS hatch closed and sealed
  - Large remote handling room shield door closed
  - PS area isolated from DS area via isolation wall
  - West wall relief sealed
  - PS area isolated from M4 beamline via isolation barrier
  - Numerous penetrations all sealed
  - HEPA filter line extracts air from PS area
  - Extinction Monitor area isolated
    - The entrance collimator aperture will have a sealed window
  - M4 beamline penetrations also sealed
  - **This will be a challenge**



- Updated airflow schematic includes individually controlled ducts to the extinction area and the remote handling room to facilitate better control of air flow
  - These additional ducts are not yet represented in the MARS model, since these lines were previously tied to the proton absorber duct line

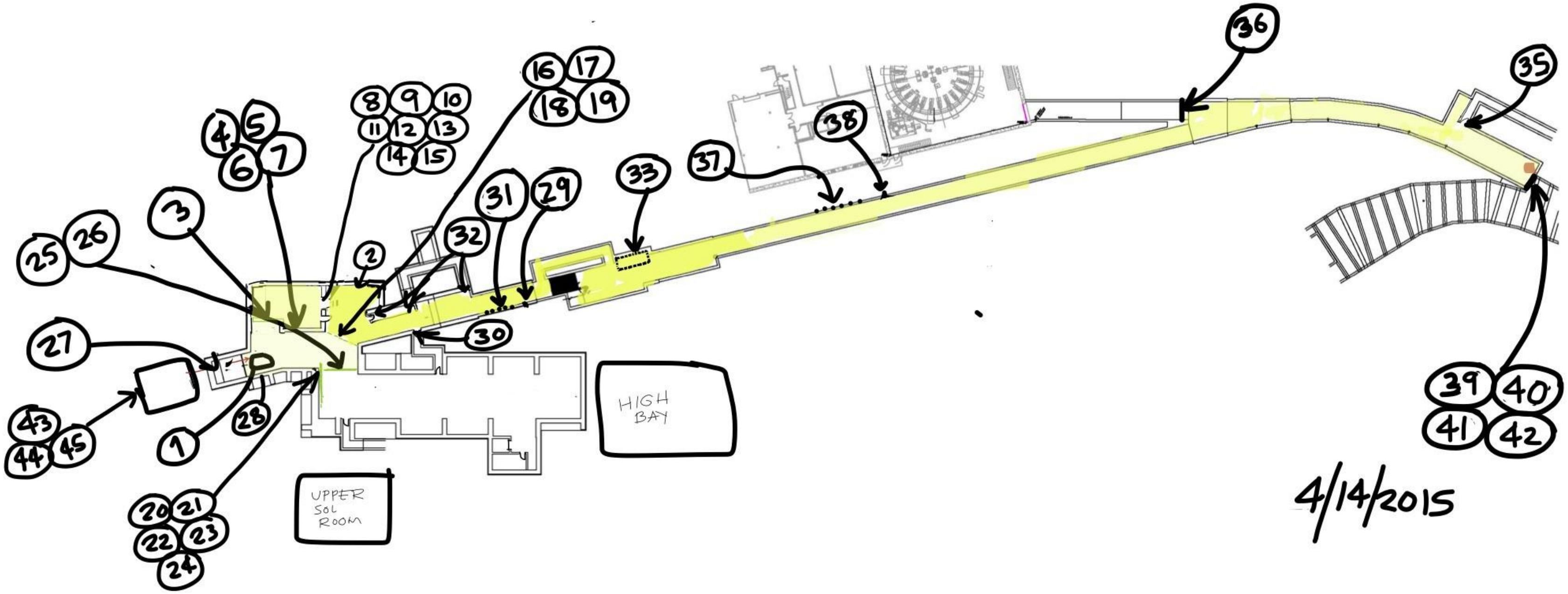

74'-8 1/2"
49'-1"
1'-6"
24'-2"
3
SC-20
8
SC-35
14'-4"
W10
W6
W7
UP
RHR
M4
30'-0"
4'-2"
2'-0"
20'-6"
10'-0"
T/MAT EL 720 - 6"
T/TOPPING EL 721 - 0"
8
SC-35
W8
W24
PS
EM
C1 SIM
W2
W2
C7
C8
C4
DS
2'-8"

Initial Air Handling Schematic
Emil Huedem 17 March 2014



Compilation of Penetrations

Emil Huedem



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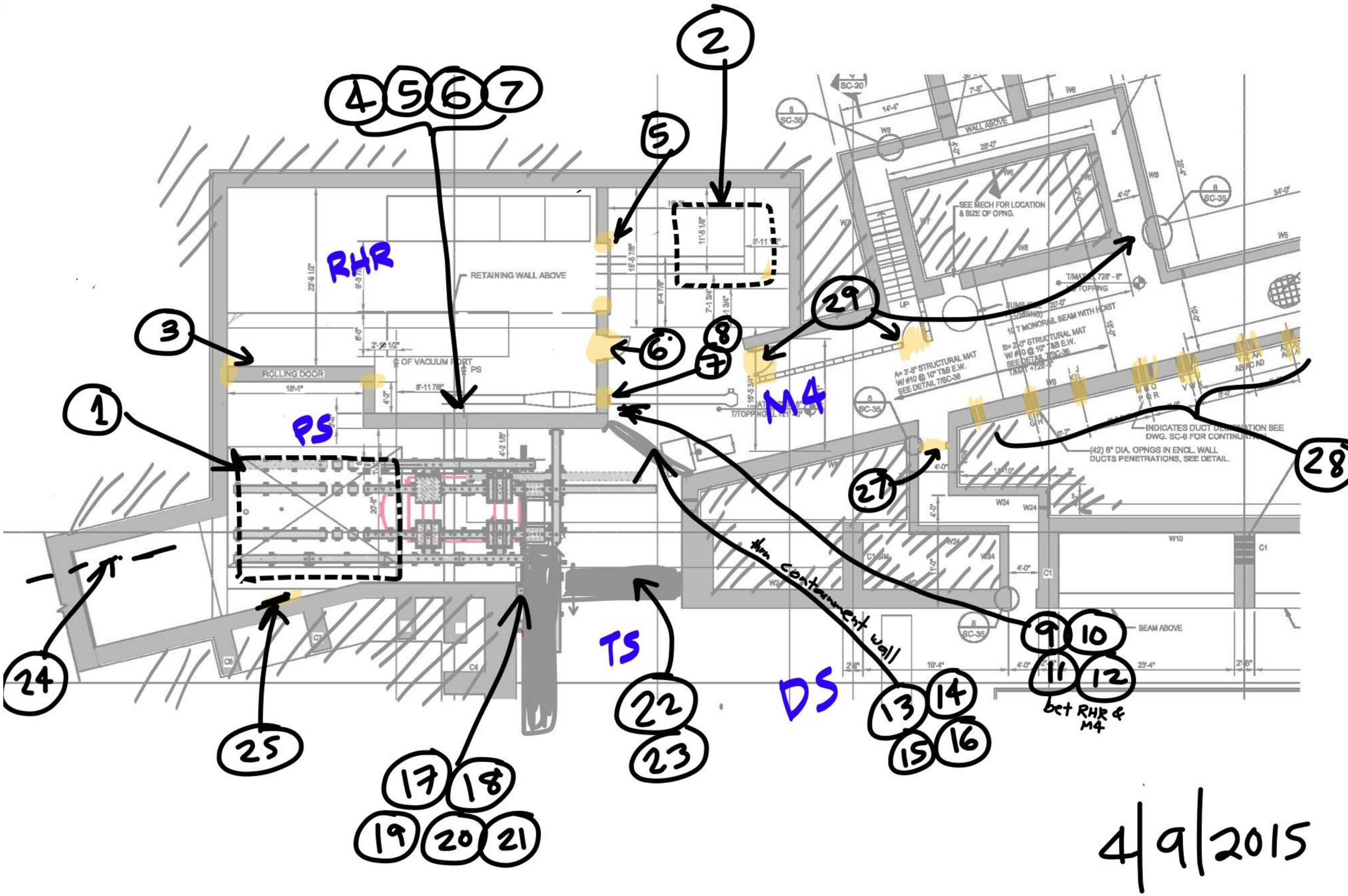

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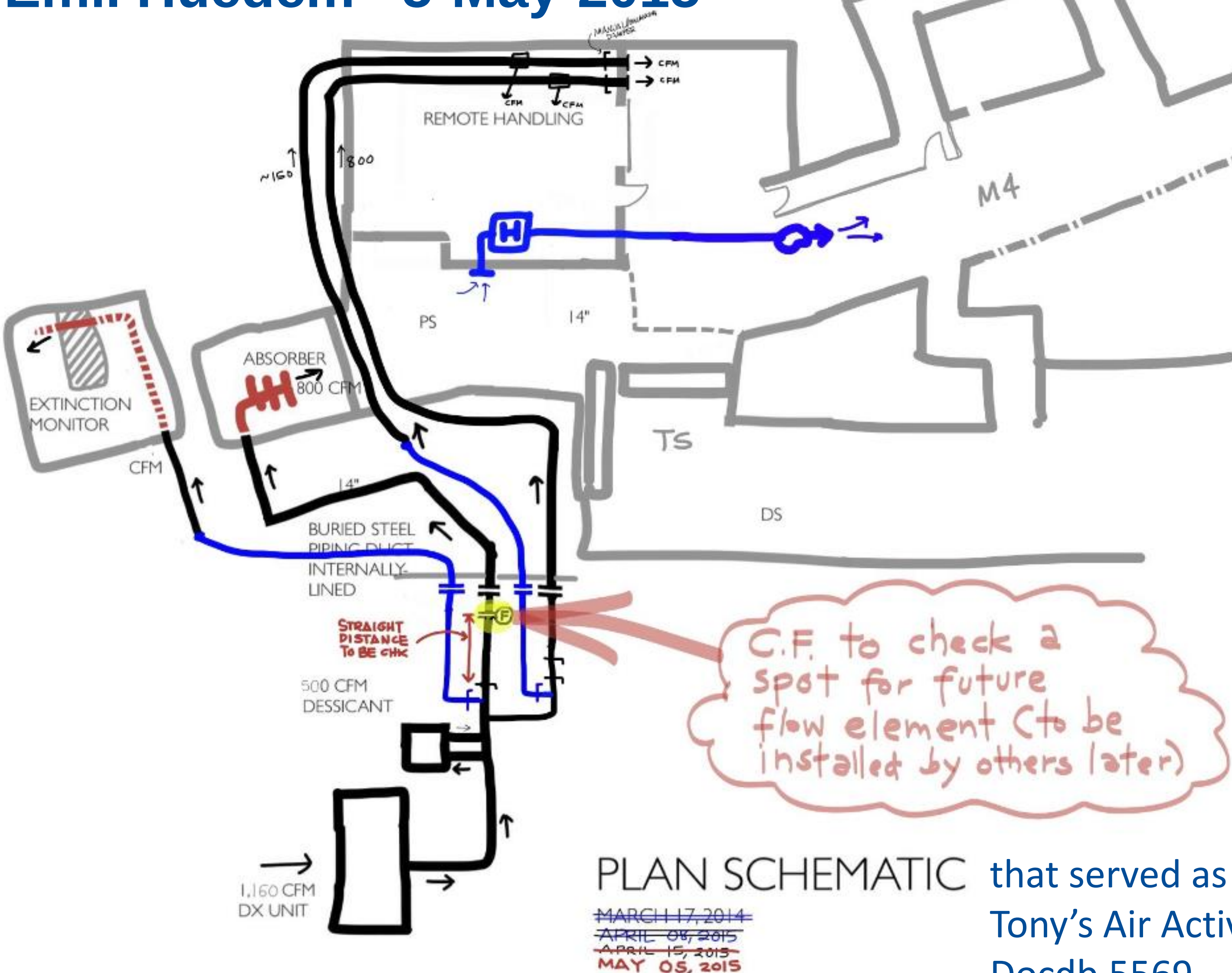
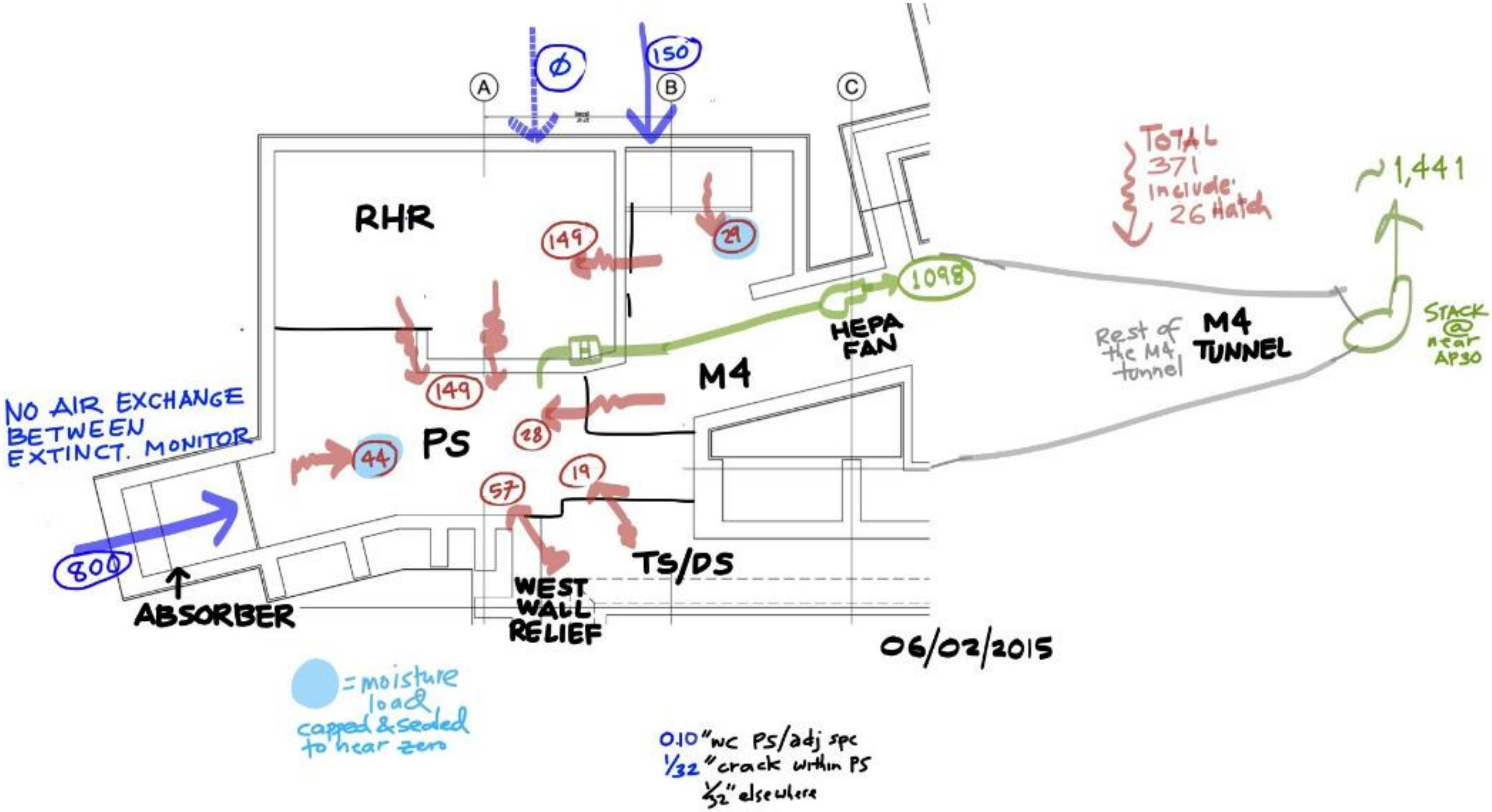
Air Handling Schematic
Emil Huedem 5-May-2015

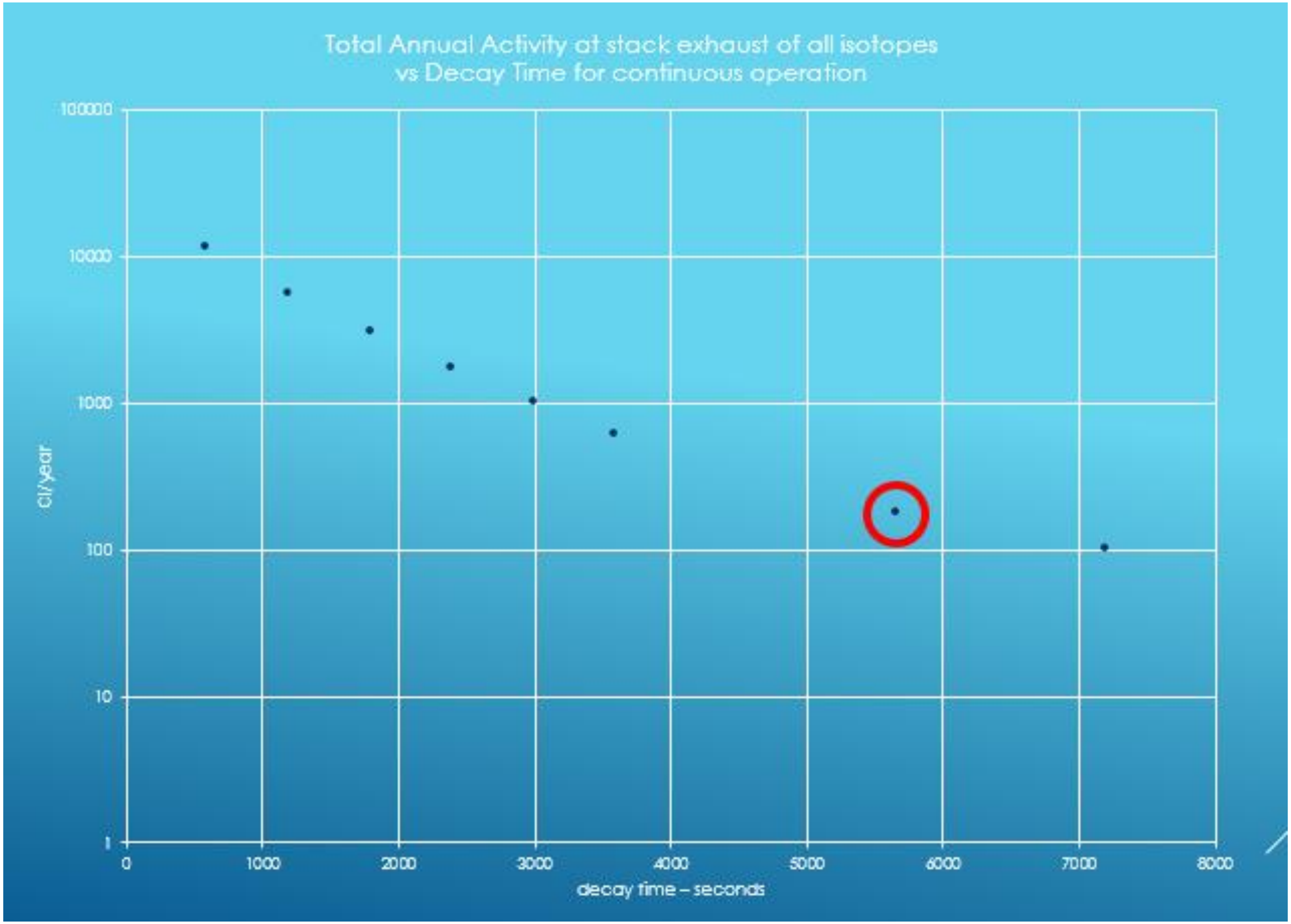


that served as input to Tony's Air Activation Analysis Docdb 5569

0.1" water differential Emil Huedem revised 2-Jun-2015



PS Area Air Activation
Tony Leveling docdb 5569 v4



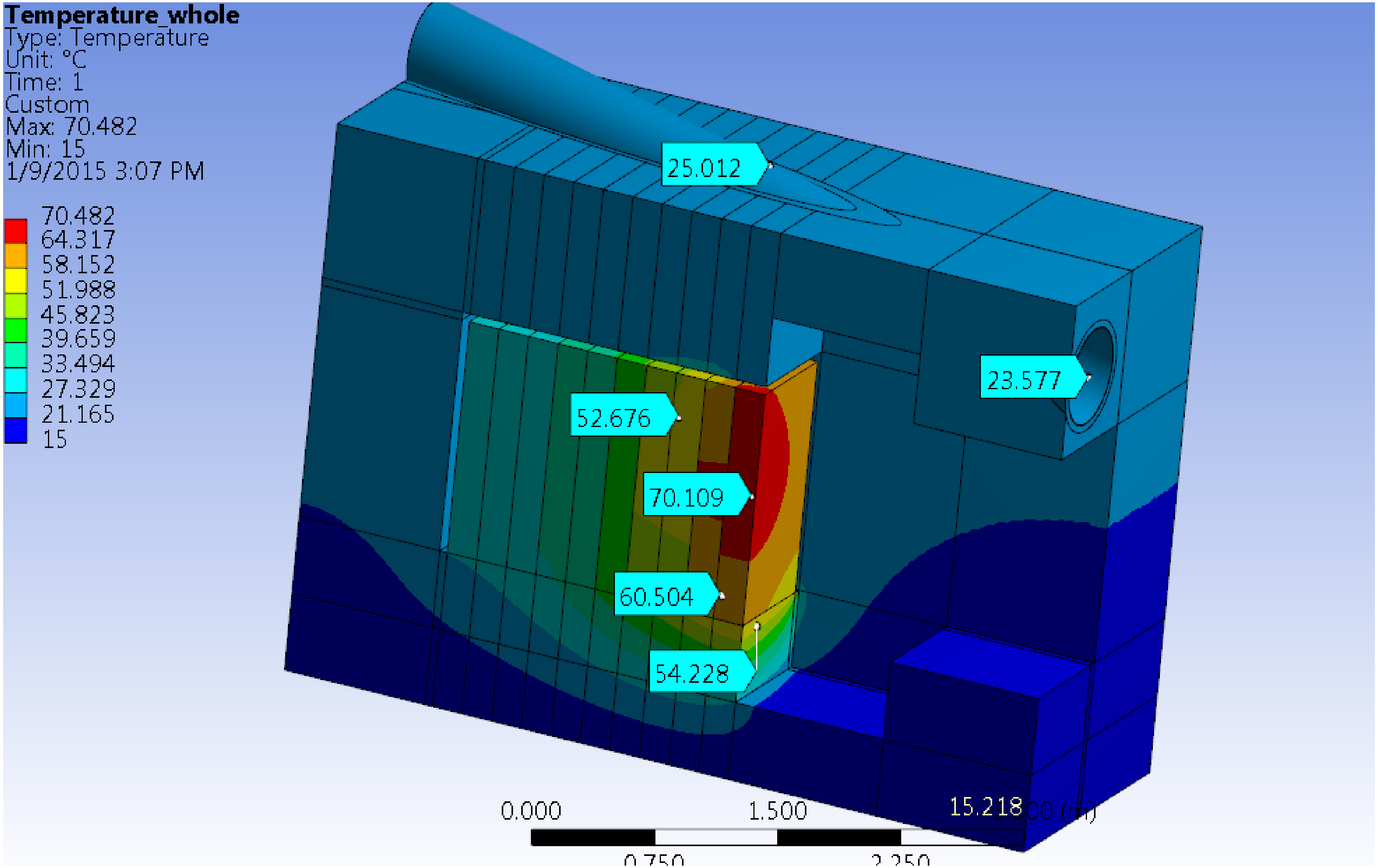
Recap of Air Handling Related Progress

- Emil has modified air handling plans to facilitate implementation
  - Plan on duct from PS area to remote handling room alcove equipped with particulate filter followed by HEPA filter (accessible from remote handling room)
  - Independent airflow control to extinction monitor room and remote handling area
  - Allow space at ground level for air flow monitoring to the proton absorber
  - Allow space at ground level for future re-routing of air flow
- Emil has attempted to evaluate penetrations and estimate leak rates so that the ventilation system can be appropriately designed and configured
  - Assume that the penetrations between the M4 beamline and the Mu2e hall can be sealed
- Tony has updated the air activation analysis (docdb 5569)
- Tony also estimated the release rate (docdb 5569)
- The Air Handling Team met with Kamran and discussed the results and plans

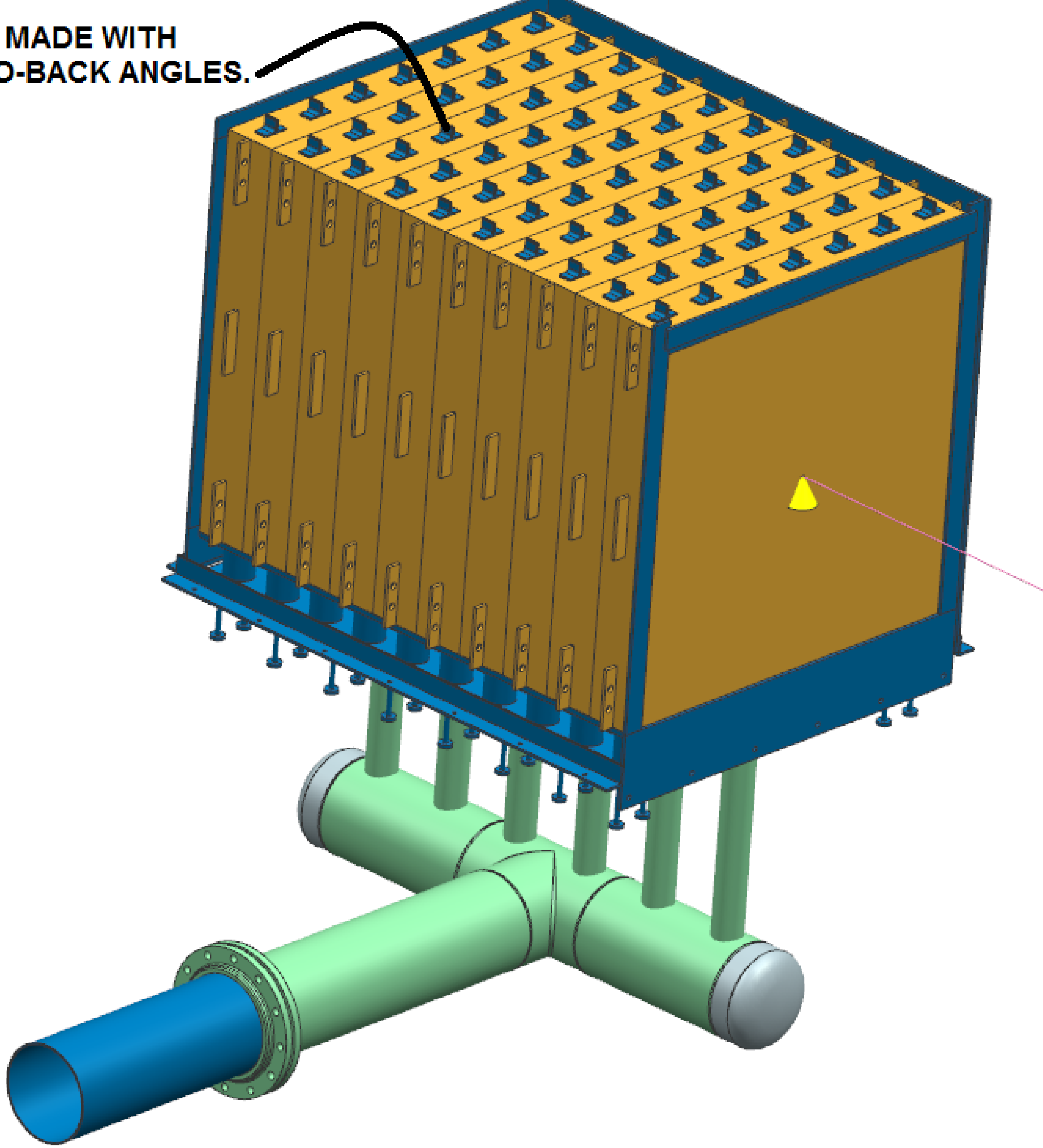
Ongoing Activities

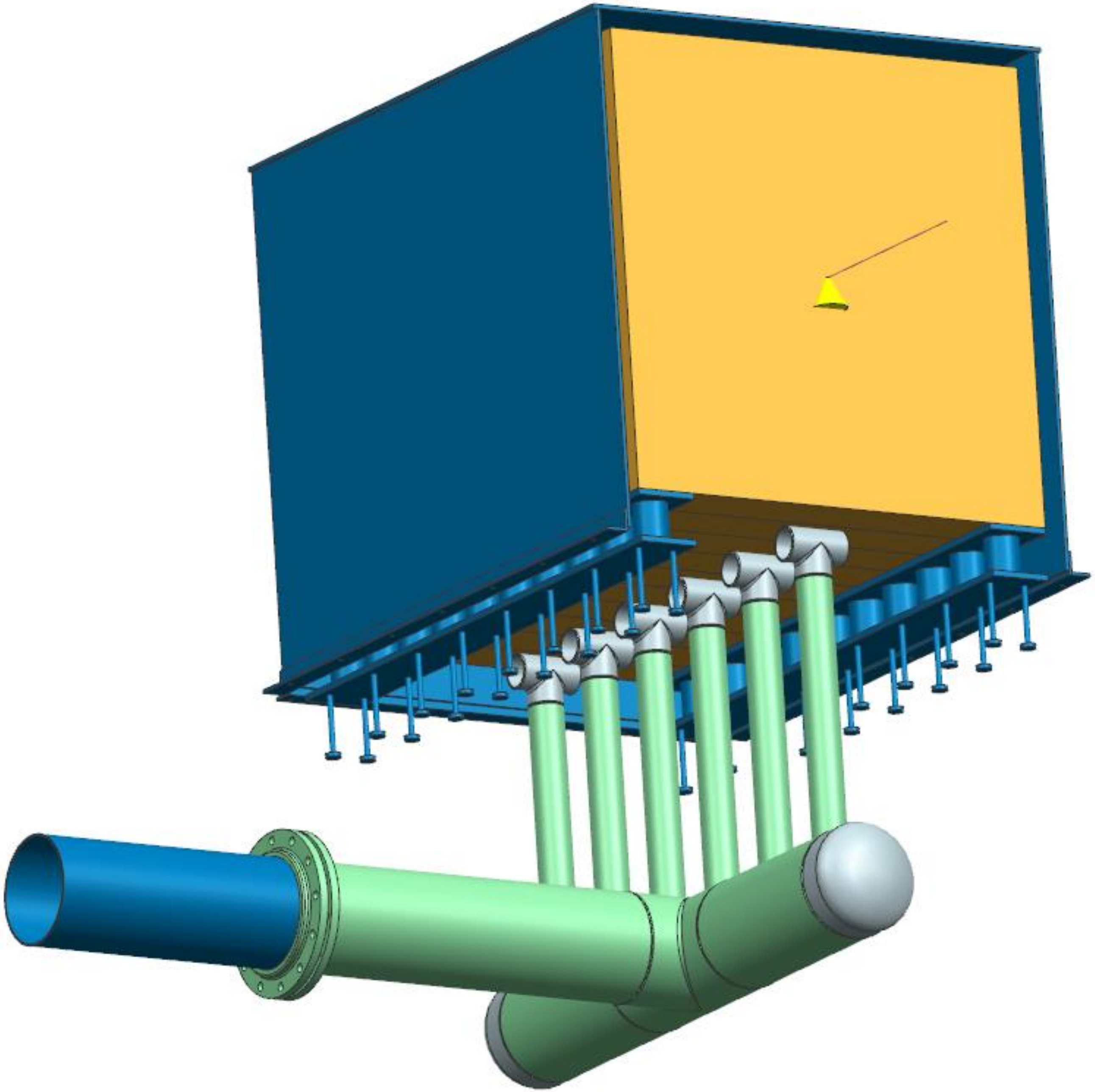
- Attempting to incorporate Kamran's comments appears to indicate that the time between activation and emission may need to be increased relative to initial expectations
  - Explore possibility of reducing air flow into proton absorber from 800CFM
    - Andy was confident that 500CFM to the proton absorber could be accommodated
    - Andy and Ang investigate possibility of 165CFM (docdb 5731)
      - At 165CFM, it is anticipated that the emissions would be < 100 Ci/year
      - Concrete temperature under upstream plate reaches 137C
        - Changing support standoff pipes to stainless steel reduced peak concrete temperature to 104.5C (conduction only) and absorber rises to 184C
      - Including radiation (in addition to conduction) will reduce peak temperature to 95.4C
      - Ang recommends adopting stainless steel as the material for the standoffs
    - Looks like 165CFM is about the low limit of acceptable airflow to the proton absorber in the normal running conditions

Proton Absorber Analysis as of January 2015
Ang Lee and Andy Stefanik   docdb 5048



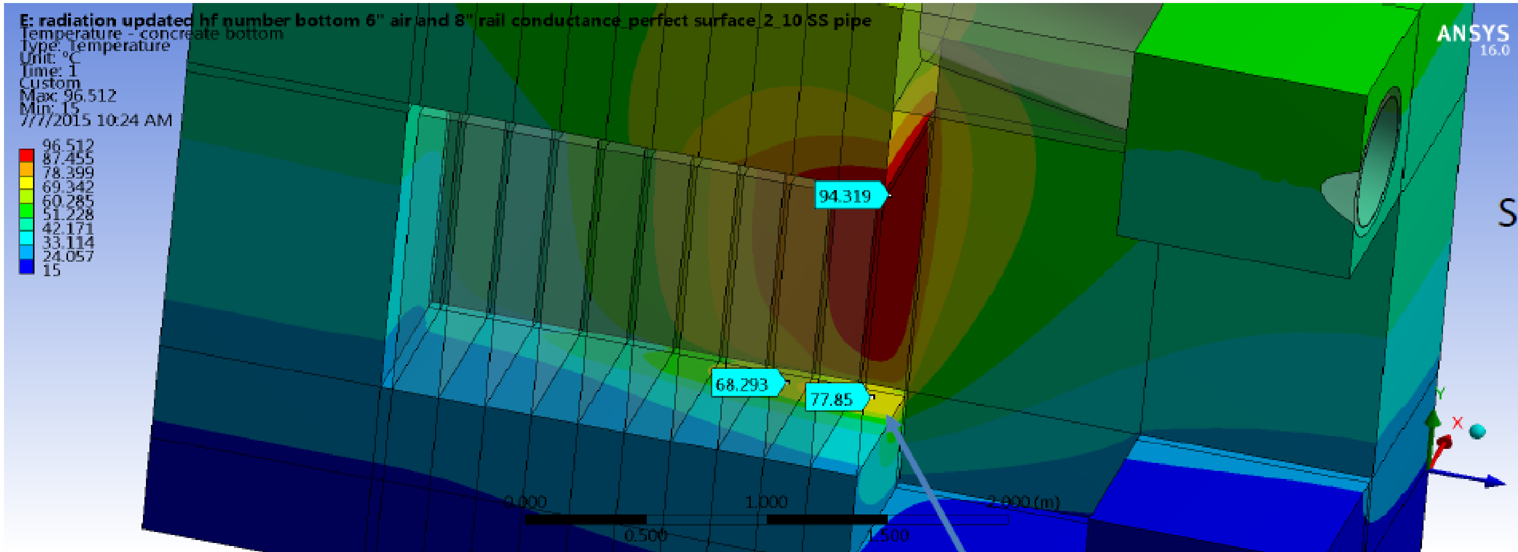
2" TEES MADE WITH
BACK-TO-BACK ANGLES.





20 Stainless steel pipes (10 per each side)radiation effect is on (top + two side surface)

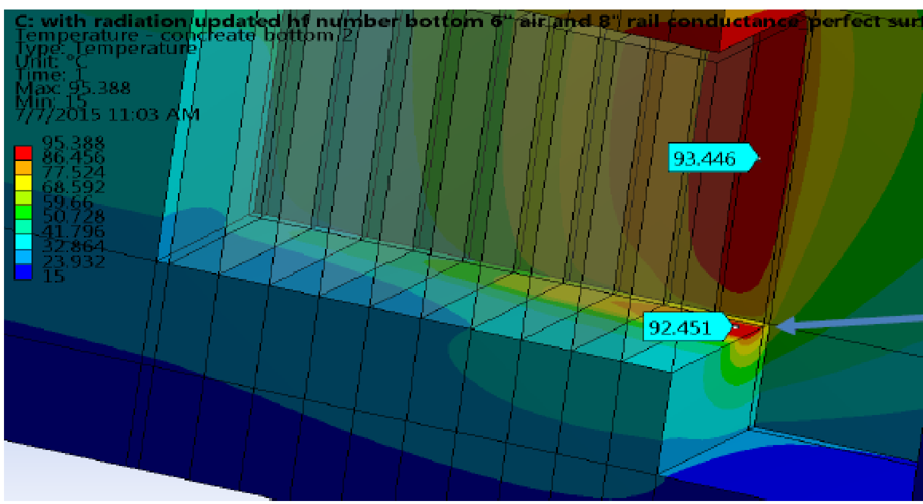
Docdb 5371
Andy Stefanik and Ang Lee



SS pipe

- Analysis with airflow reduced to 165 CFM
- It is believed to be prudent to maintain the concrete temperature below 100C

With stainless steel pipe, the **bottom surface** concrete temperature is lower (78 C).



Regular steel pipe

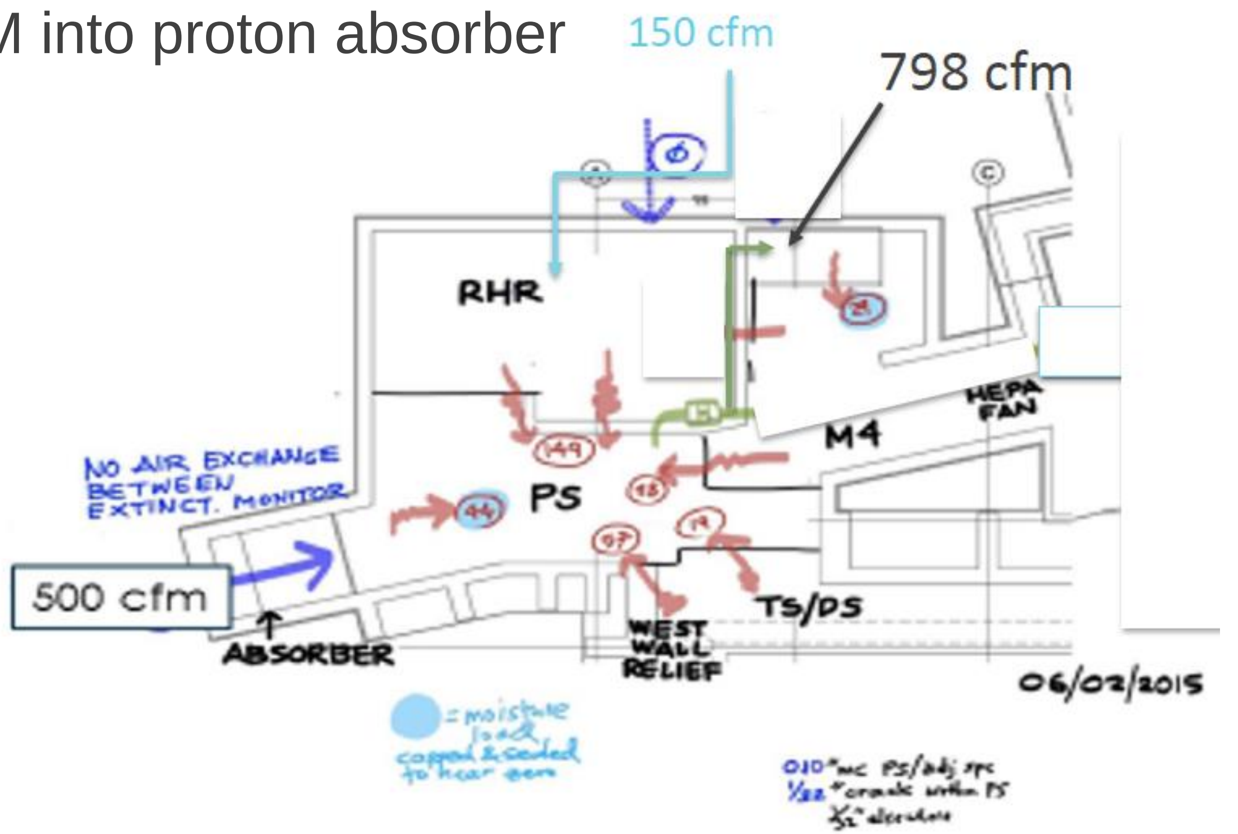
With a regular steel pipe in the rail case, the concreate bottom T=93 C.

However, Tmax of concrete stays about the same for both cases. 18

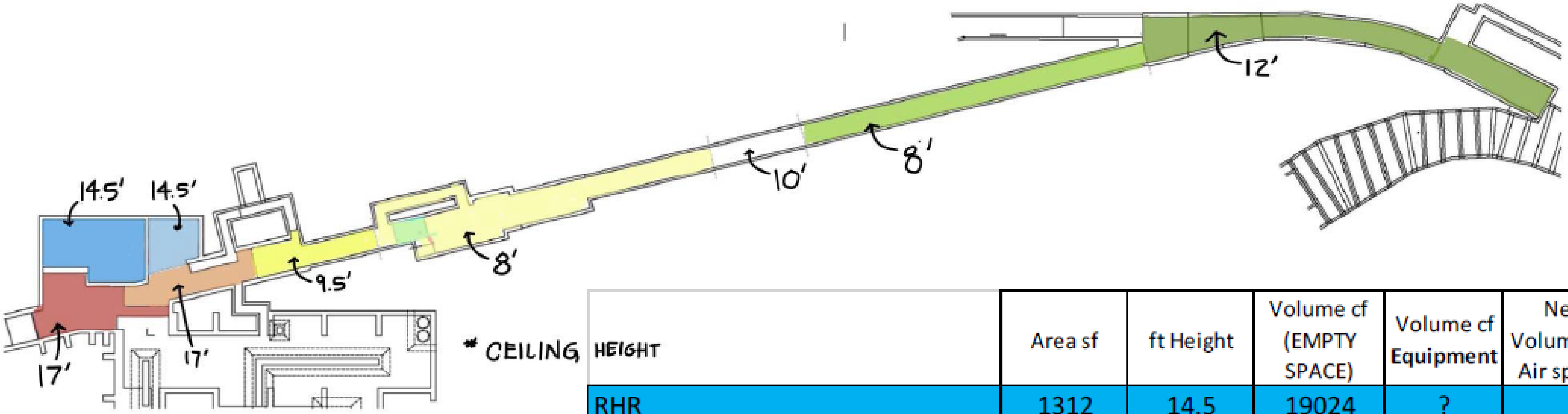
Proton Absorber Related Updates?

- Include thin stainless steel sheet on the upstream surface of the absorber
  - Further suppress dispersion of particulates from the proton absorber
- Exploring impact of reduced airflow to the proton absorber
  - Requesting SS pipe stand-offs to reduce heat transfer to concrete
  - Anticipate ½” gap between top of absorber and underside of steel plate shielding above the absorber
  - Thermally isolate sides of proton absorber from surrounding concrete
    - Install extractable shims used during concrete pour and extracted prior to operations to thermally isolate proton absorber from surrounding concrete
  - The accident conditions should be revisited with the updated airflow
  - Does the potential impact of operating at higher temperature require evaluation of the potential impact on the extinction monitor channel?

- Kamran was provided with a version of the airflow and air activation information so that he can evaluate the anticipated release rate (docdb 5739)
  - Assumed 500 CFM into proton absorber



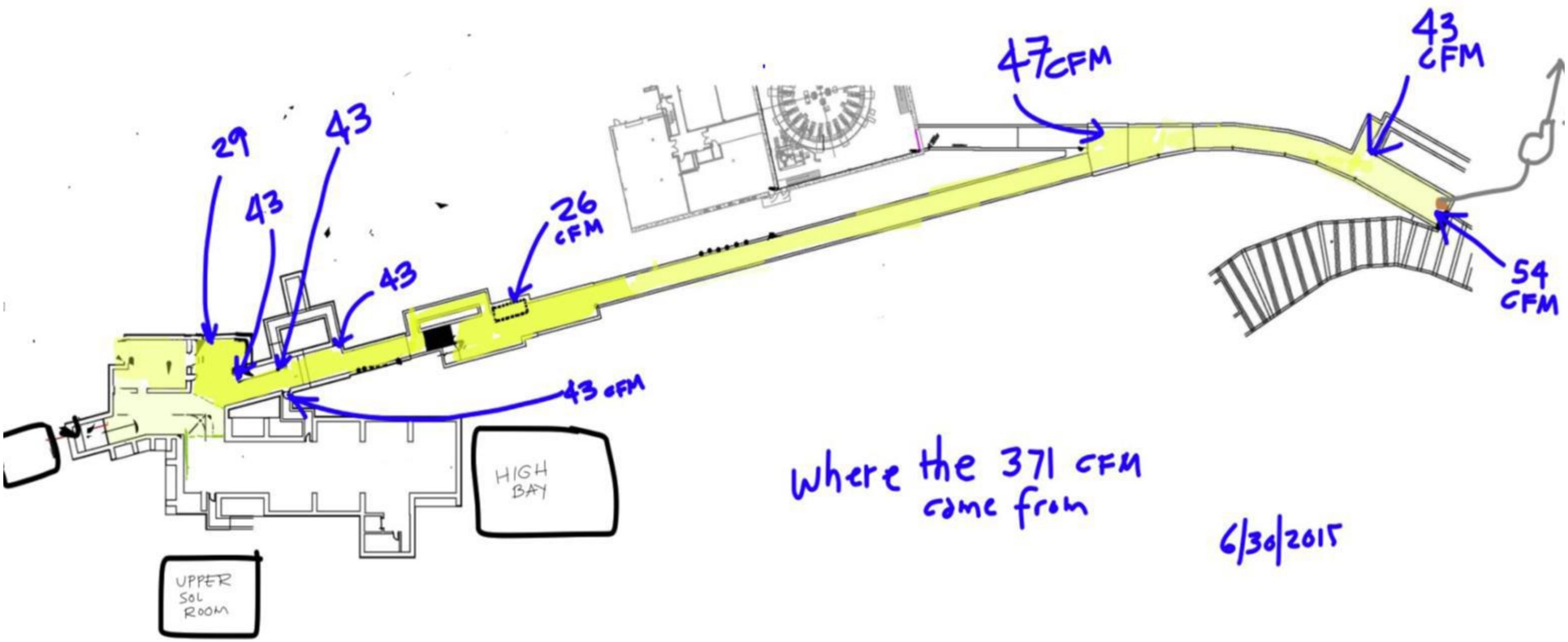
Revised Estimates of Various Volumes
Emil 2-Jun-2015



	Area sf	ft Height	Volume cf (EMPTY SPACE)	Volume cf Equipment	Net Volume of Air space
RHR	1312	14.5	19024	?	
absorber	not included				0
begin absorber & PS hall	1092	17	18564	844	17720
M4 adj to RHR	542	14.5	7859	0	7859
this is where we have high ceiling	791	17	13447	?	
tunnel begin where height is lower	718	9.5	6821	?	
tunnel	1866	8	14928	?	
tunnel	450	10	4500	?	
tunnel	1646	8	13168	?	
wye (w tunnel to MC1) to delivery	2869	12	34428	?	
	total including RHR		**132,739**	**CF**	
	total excluding RHR		**113,715**	**CF**	
	total exlsuing RHR/PS		**87,292**	**CF**	

Mu2e Radioactive Air Emissions Estimates Study
Kamran Vaziri docdb 5739 v3

798	827	913	956	982	1126
798	798+29	827+43+43	913+43	956+26	982+47+43+54



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Mu2e Radioactive Air Emissions Estimates Study
Kamran Vaziri docdb 5739 v3

July 7/2015	+RHR 150cfm	+RHR 100cfm	+RHR 50cfm	+RHR 0.0 cfm	+RHR & weye 0.0 cfm
Absorber air flow	Annual Release	Annual Release	Annual Release	Annual Release	Annual Release
(cfm)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)
800	604	562	521	479	427
700	521	479	438	397	349
600	438	397	357	318	274
500	357	318	280	243	205
400	280	243	208	175	143
300	208	175	144	116	92
250	175	144	116	91	71
200	144	116	91	69	53
165	124	98	75	56	42
100	90	69	51	36	27
50	69	51	36	24	18

Mu2e Radioactive Air Emissions Estimates Study
Kamran Vaziri docdb 5739 v3

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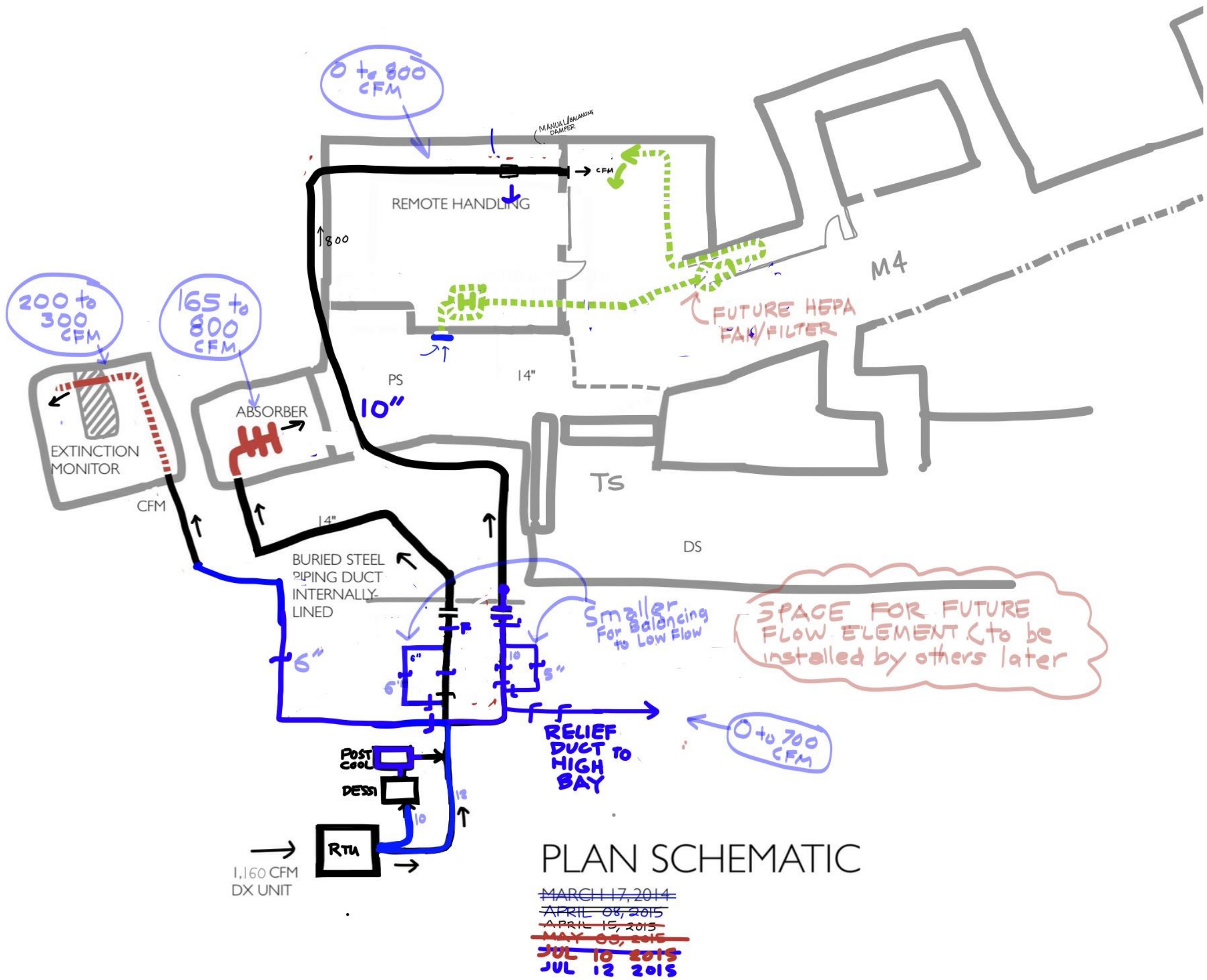
165	124	98	75	56	42
100	90	69	51	36	27
50	69	51	36	24	18

- Anticipated operating range for proton absorber airflows between 165 and 300 CFM likely results in acceptable activated air emission levels (assuming the other pressure differentials and air leak rates can be achieved)

Current Air Handling Schematic
Emil Huedem 12-July-2015



Other Open Questions and Topics be Revisited

- Will reduced airflow in the PS area and M4 beamline generate complications due to humidity or acid?
- May benefit from refining of inputs into the air activation emission analysis
  - VESDA in the remote handling room and in the M4 beamline?
  - Include additional penetrations for solenoid cryostat insulating vacuum system
    - Do the solenoid cryostat insulating vacuum pumps have cold traps? If so, where are they vented?
  - Can the gas nitrogen from the muon beamline diffusion pump cold trap be vented directly to the outside or is this also vented in the beamline
  - How about the muon beamline vacuum backing pump exhaust?
    - Assuming that gets vented into the M4 beamline
  - Do power conduits have the potential to represent air leaks between areas?
- The Oxygen Deficiency Hazard analysis will need to be revisited
  - Current proposal is to disable the ODH air supply to the PS area prior to beam operations
    - Seal air inlet to eliminate this air source (for pressure differential)
    - Reduces potential to spread activated particulates
  - The PS Area will very likely be at least ODH class 1 after that transition
  - Are there implications for activities in this area during a power outage?

- Time and resources for instrumentation to monitor pressure differentials and airflows?
- Time and resources for sealing and verification of seals in the installation schedule?

Air Handling Summary

- Limiting the emission of activated air will require careful control of air pressure differentials and air leaks
  - Isolate the PS area
  - Disable the PS area ODH ventilation system prior to first beam
    - PS area will likely be at least ODH class 1
  - Introduction of a dedicated duct and HEPA filter system on the PS area
  - Installing and maintaining seals on numerous hatches, doors and penetrations
    - Some of these penetrations will be buried under substantial shielding
  - Anticipate that establishing and maintaining this pressure differential will be a challenge
- Kamran's assessment of the radioactive air emissions now available, and confirms
  - Will very likely need to re-direct or reduce airflow to the proton absorber
    - Looks like ~250 CFM may be an appropriate initial value if the airflow to remote handling area is reduced during beam operations
    - Aim to provide capability for range of airflow to the proton absorber from 165 CFM through 800 CFM
  - Air flow reduction has potential impact of the (details of) proton absorber design
- Assuming the proton absorber can sustain reduced airflows and the required air seals can be established, the activated air emissions due to Mu2e operations appear likely to achieve an acceptable fraction of the lab's quota

Backup Slides

- Backup slides follow

Other Potentially Open Questions

- Beam Commissioning Conditions?
- Access Conditions?
- When is negative pressure in the PS area required?
  - Only during beam operations (and associated transitions) or also at other times after irradiation
    - What happen when if or when it becomes necessary to open the PS hatch or compromise the TS isolation wall
    - Perhaps negative pressure only necessary during beam operations, transitions and whenever any of the upstream muon beamline ports are open?
      - neutral pressure differential in other conditions?
- Negative pressure in PS area primarily achieved via HEPA filter line (and local sealing)
  - requires coordination of access doors into remote handling room
  - when the large remote handling room door is open, the service entries may need to remain closed unless we attempt to reduce pressure in the entire region
- Is there a personnel door in the access via the M4 line? If so, under what conditions can that door be used?
- Does the Remote Handling Room need to be maintained at negative pressure relative to the M4 area?
  - If so when?

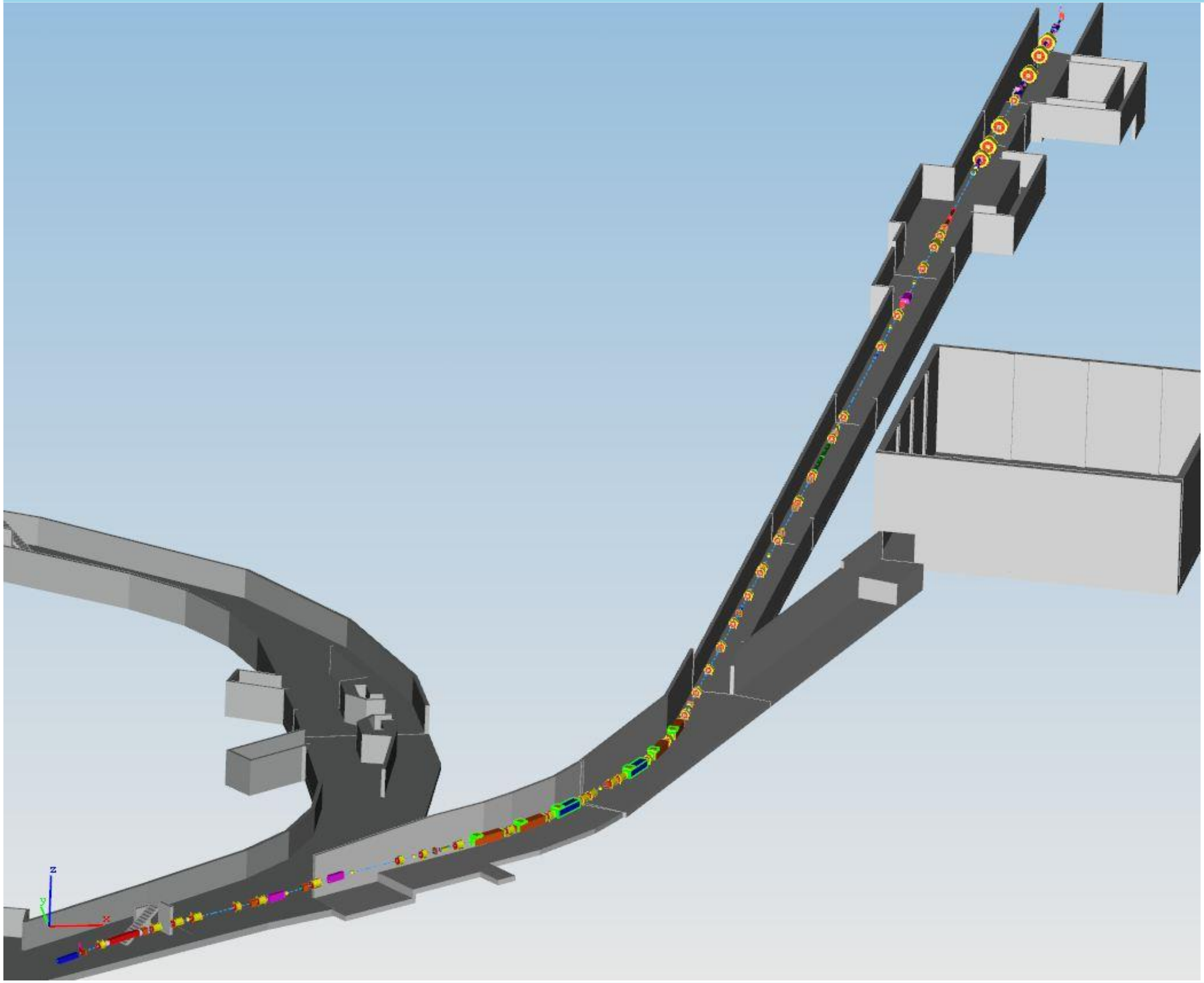
Additional Progress

- Tony has evaluated residual dose rates in the PS area and remote handling room (docdb 5629, 5572, 5553, 5543, and 5471)
- Tony has also investigated contamination in the PS area (docdb 5599)
  - 0.5nCi is the threshold for control
  - Anticipating that contamination control in the PS area will be necessary

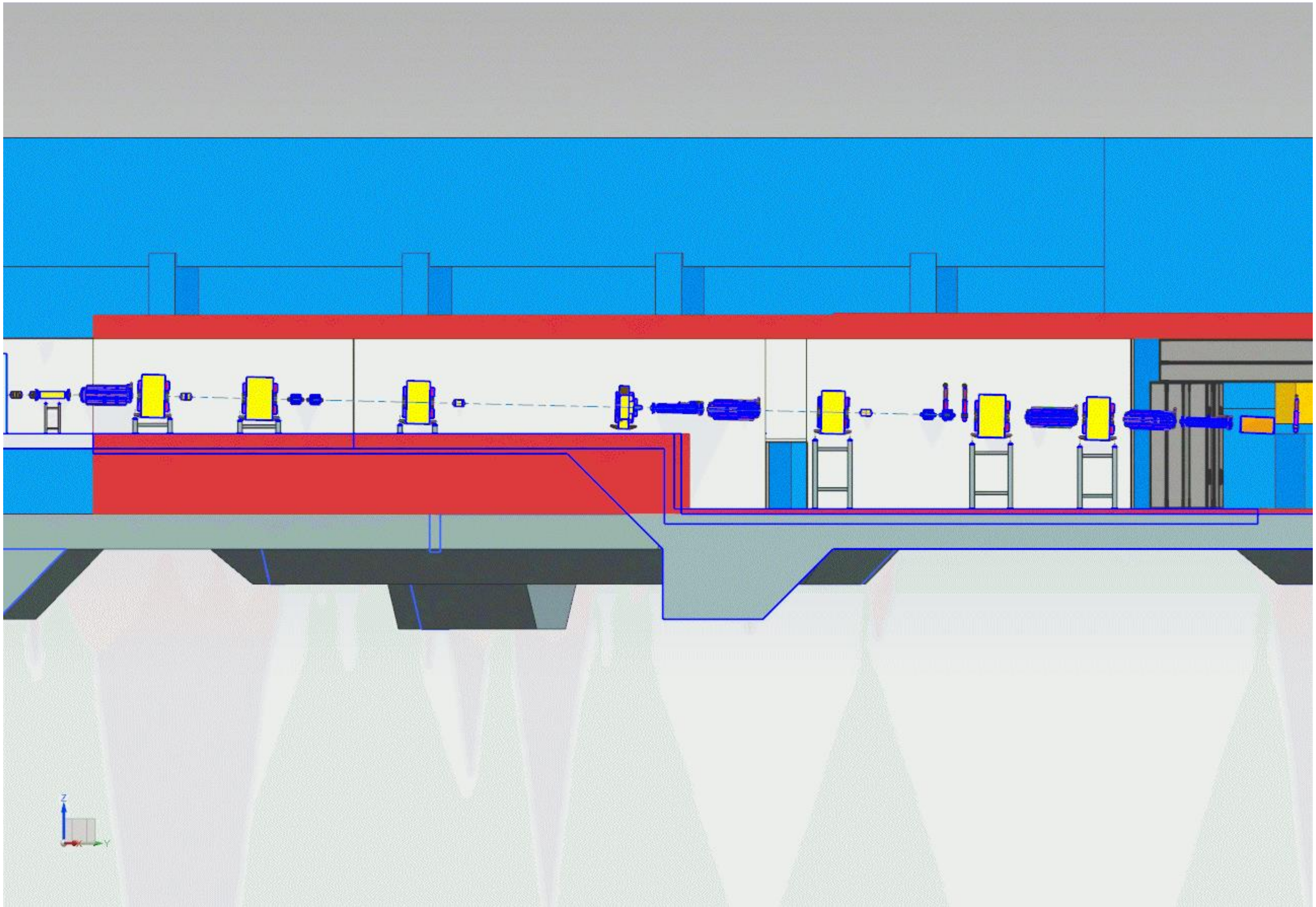
- Residual dose rates to individuals entering the PS area after beam operations will likely be substantial unless local shielding is installed
- Contamination control will also likely be necessary in the PS area

- Should the groundwater and surface water activation assessments also be revisited?
  - Note that the building design includes an independent sump to trap any fluids collected from the floor drains for testing prior to pumping

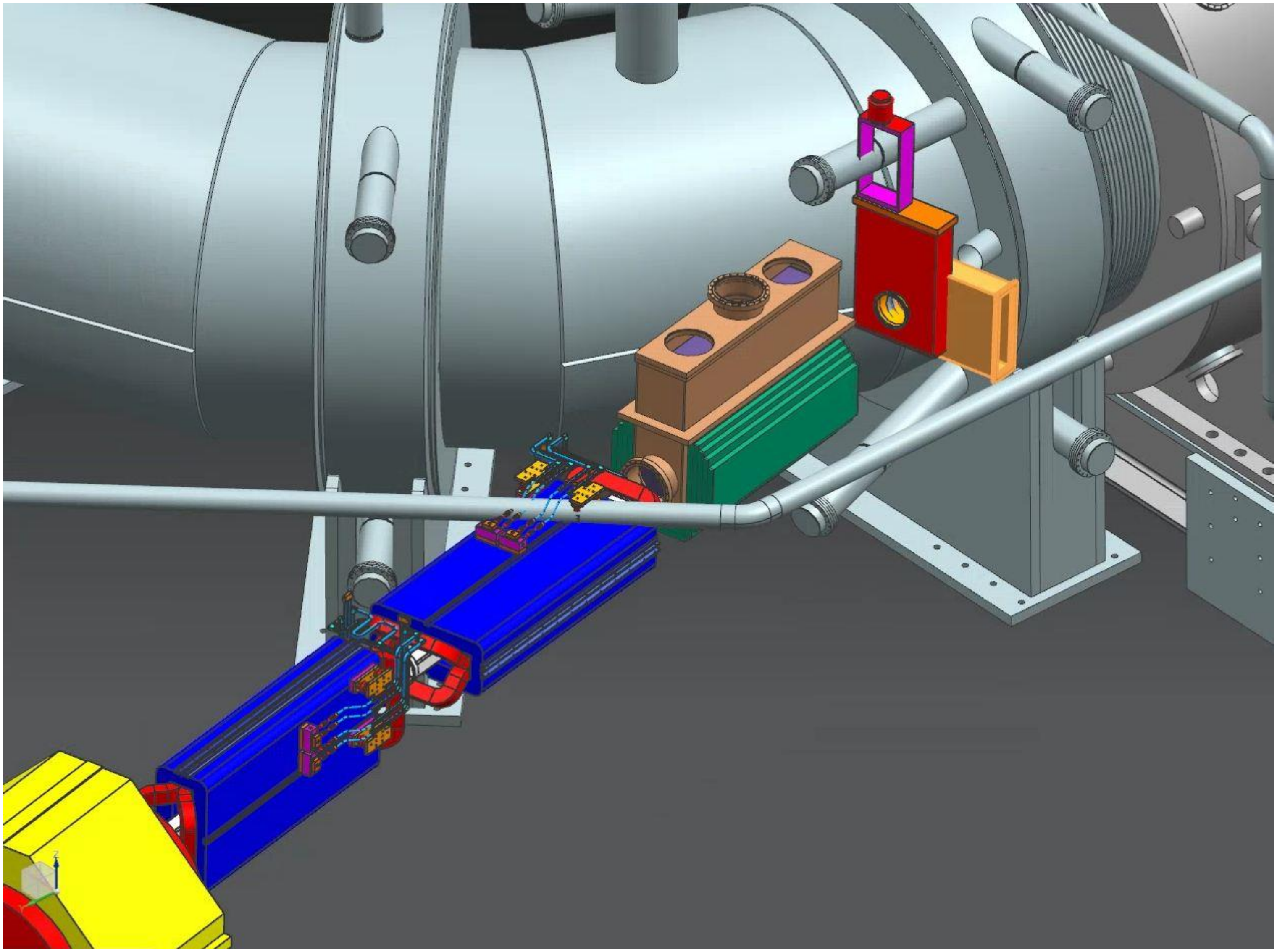
M4 Beamline Final Focus Moveable Stands
Dean Still   docdb 5563



M4 Beamline Final Focus Moveable Stands
Dean Still docdb 5563



M4 Beamline Components
Dean Still   docdb 5719



MU2E "QUANTIFYING PENETRATIONS FOR AIRFLOW" APRIL 28 2015, EH

press diff bet RHR & PS	0.10	"wc
press diff bet M4 & adj	0.05	"wc
press diff bet RHR & M4	0.05	"wc

shaded blue=outdoor source

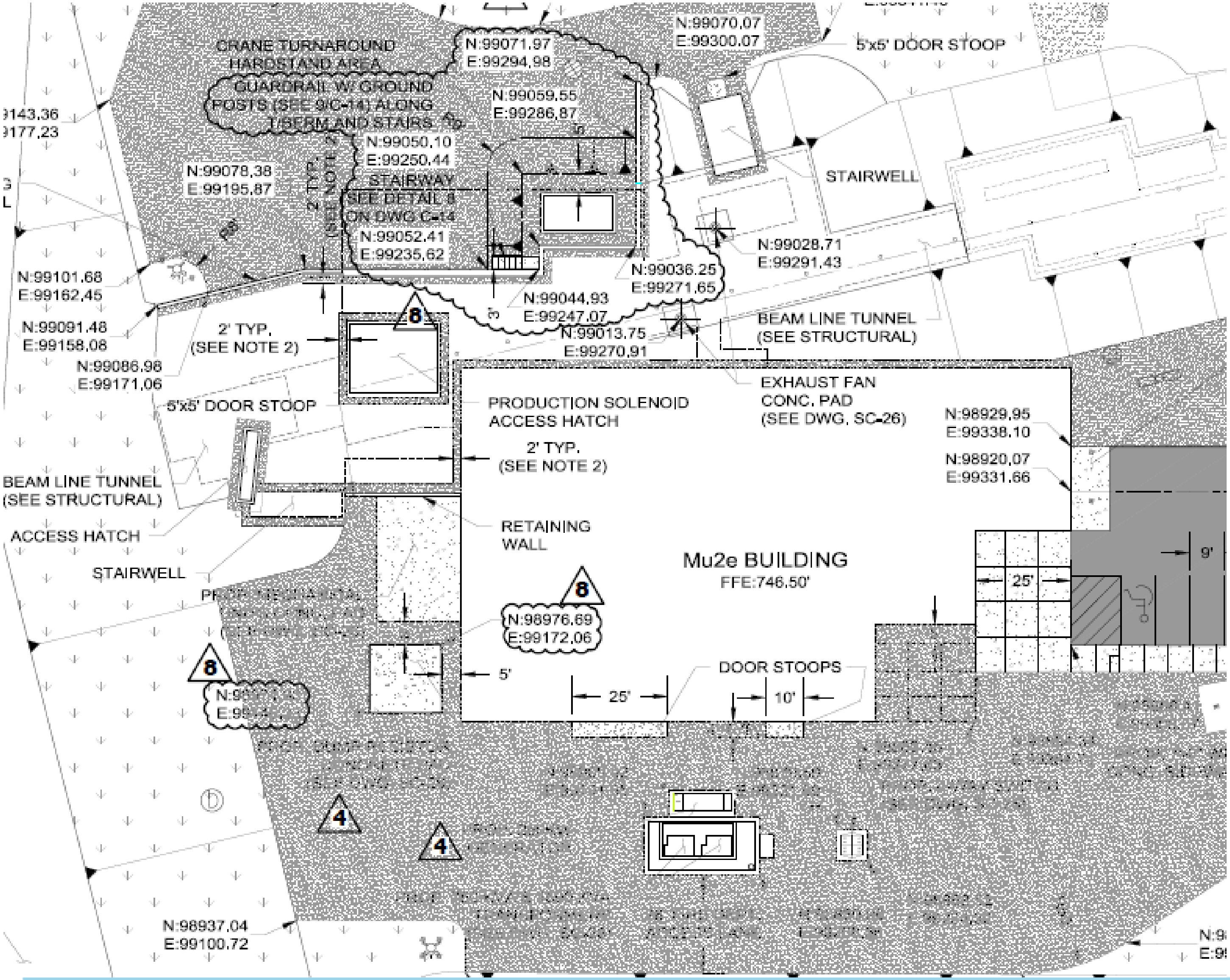
No.	QUANTIFYING PENETRATIONS BET SPACES	QTY	SIZE	TYPE	CRACK inch	Leakage CFM	Note	assumed	TOTALS
	PS and absorber & hatch								844
	Airflow supply to Absorber					800			
1	Hatch (will be capped, sealed tight)	1	22'-10" x 18'-2" capped	rectangular	1/128	44	b	assumed capped, no wind impact, minimal perimeter leakage	
	PS and RHR								299
3	Rolling Door	1	18' x 14ft H (edges 13' & 17')	rectangular	1/16	258	b	perim 17+13+13+17	
4	HEPA Duct grille	1	24 x 15	rectangular	0	NA	NA	easy to seal	
5	upstream muon beamline high vacuum line	1	24" outer diameter	circular, but will be positioned at an angle	1/16	27	b	6.3'LF x crack	
6	muon beamline roughing line	1	6" diameter	circular	1/16	7	b	1.6' LF x crack	
7	production solenoid cryostat insulating vacuum pumping line	1	6" diameter?	circular	1/16	7	b	1.6' LF x crack	
	PS and M4 TUNNEL (thru containment wall)								28
17	vacuum line for the HRS isolation space	1	2" diameter	circular	1/16	2	b	0.52' LF x crack	
18	primary beamline	1	5" diameter?	circular	1/16	6	b	1.39' LF x crack	
19	services for any primary beamline elements downstream of the barrier that defines the boundary between the two spaces	?	?	?		20	b	placeholder	
	PS and WEST WALL RELIEF *[2ft wide x 8'-6" tall]*								57
20	Production solenoid cryo line	1	10" diameter?	circular	1/16	11	b	2.6' LF x crack	
21	Production solenoid instrumentation line	1	5" diameter?	circular	1/16	6	b	1.39' LF x crack	
22	TSu cryo line	1	10" diameter?	circular	1/16	11	b	2.6' LF x crack	
23	muon beamline roughing line	1	6" diameter	circular	1/16	7	b	1.57'LF x crack	
24	instrumentation and data lines?	2	10" diameter ducts?	circular	1/16	22	b	(2) 2.6' LF x crack	
	PS and TS/DS								19
25	TS cryostat	1	Rectangular opening in shield pile is 103" wide by 152" tall, the TS is at least 53" diameter	TS approximately circular	1/16	19	b	4.4' LF x crack	
26	hydrostatic level	?	?	?			b		
	PS and SOUTH CONC WALL								
28	ODH supply grille	1	34" x 34"	rectangular	0	NA	b	assume blanked off/sealed	
								HEPA FAN TOTAL	1247

	RHR and M4 TUNNEL							221
8	Shield Wall?	1	10' x 13' H	rectangular	1/16	140	b	perim 10+13+10+13
9	Door	1	3' x 7'	rectangular	1/16	61	b	perim 3+7+3+7
10	HEPA line / ductwork	1	16" or rectang equiv	either	0	NA	na	easy to seal
11	CHW for the upstream muon beamline diffusion pump	2	2" + 1"insulation	circular	1/16	5	b	(2) 0.8' LF x crack
12	liquid nitrogen supply and exhaust for the upstream muon beamline cold trap	2	one inlet and one exhaust 2" diameter each	circular	1/16	3	b	(2) 0.5' LF x crack
13	power, controls and monitoring for the upstream muon beamline vacuum	1	6" by 4" cable tray	various shapes	1/16	5	b	1.67' LF x crack
14	the upstream muon beamline vacuum vent line	1	4" diameter	circular	1/16	3	b	1'LF x crack
15	possibility of power and controls for a production solenoid cryostat vacuum pumping system	1	6" diameter duct?	circular	1/16	5	b	1.57' LF x crack

	M4 (near RHR) to Outside							262
2	Hatch (will be capped)	1	9'-2" x 18'-2" (covered by QTY - 9'x1.5'x1.5' blocks & capped)	rectangular	1/128	21	b	assumed capped, no wind impact, minimal perimeter leakage
	M4 (near RHR)							
32	Door (near Mu2e))	3	3' x 7'	rectangular	1/32	91	b	3 (perim 3+7+3+7) x crack
30	Door	1	3' x 7' (2 in parallel)	rectangular	1/32	30	b	(perim 3+7+3+7) x crack
	M4 TUNNEL & DS							
29	PVC Carrier Pipe	3	8"	circular	0	NA	na	
	M4 TUNNEL & HIGH BAY							
31	Conduits/ Electrical Ducts	42	6"	circular	0	NA	g	
	M4 TUNNEL & OUTSIDE							
33	Hatch (will be capped)	1	18'-4 x 5'-6"	rectangular	1/128	18	b	assumed capped, no wind impact, minimal perimeter leakage
34	Survey Risers (will be capped)	2			0	NA	na	
35	Door (near Delivery ring)	1	3' x 7'	rectangular	1/32	30	b	(perim 3+7+3+7) x crack
	M4 TUNNEL & MC1 Bldg and M-5 Tunnel)							
36	Door	1	4' x 7'	rectangular	1/32	33	b	(perim 4+7+4+7) x crack
37	Conduits	36	6"	circular	0	NA	g	
38	Conduits	2	8"	circular	0	NA	g	
	M4 TUNNEL & Delivery Ring (WALL is 7'-10 x 8'-0 TALL)							
39	Beampipe	1	4"	circular	1/32	2	b	1'LF x crack
40	LCW Pipes	2	4"	circular	1/32	3	b	(2) 1'LF x crack
41	Conduits	?	?	circular	0	NA	g	
42	Cable Trays	3	4"tall x 18" wide	rectangular	1/16	33	b	perim 3x (4"+18"+4"+18")
								STACK FAN TOTAL 1333

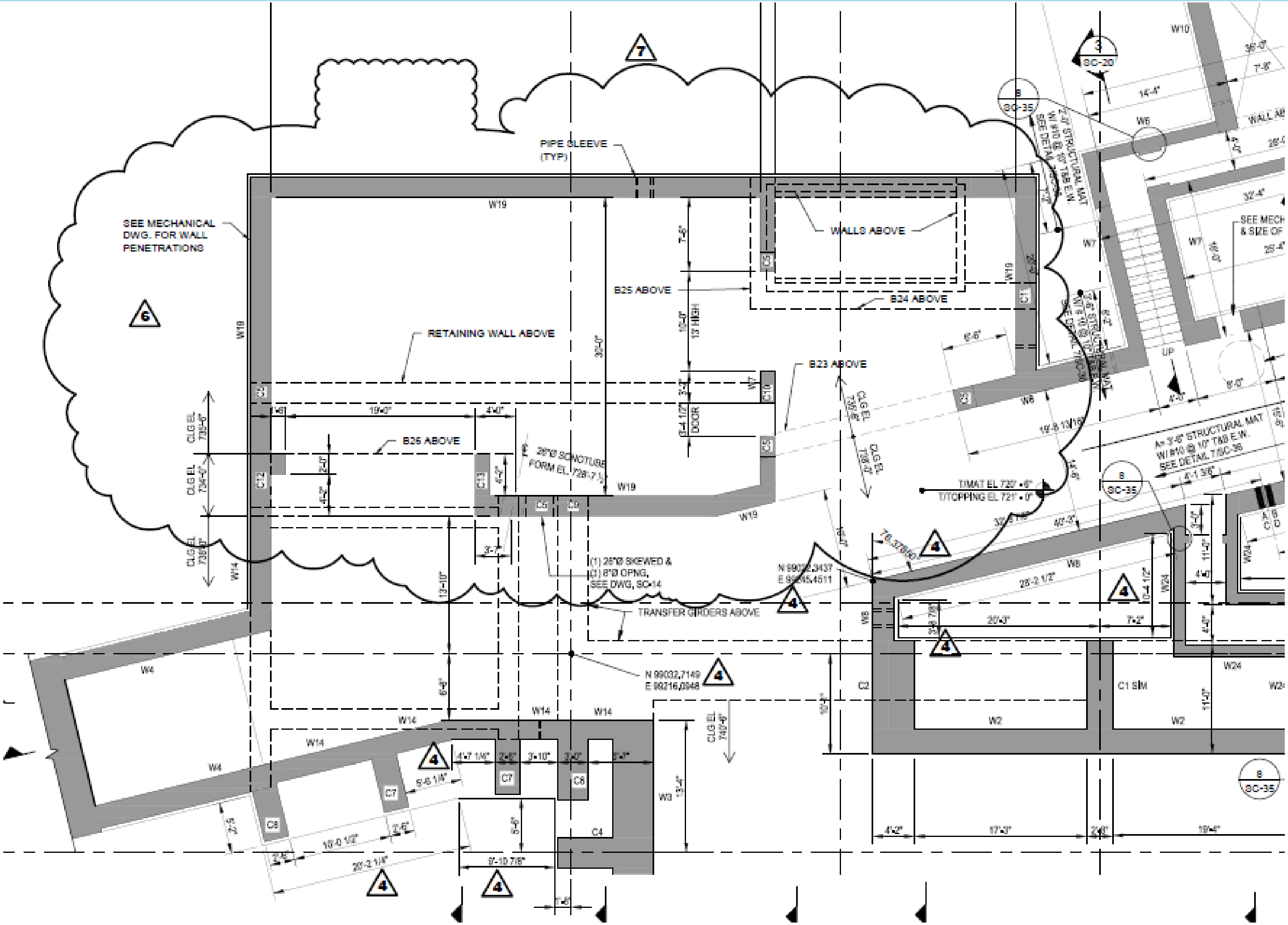
supply to rhr	77
supply to m4 near rhr	73

Docdb 5743



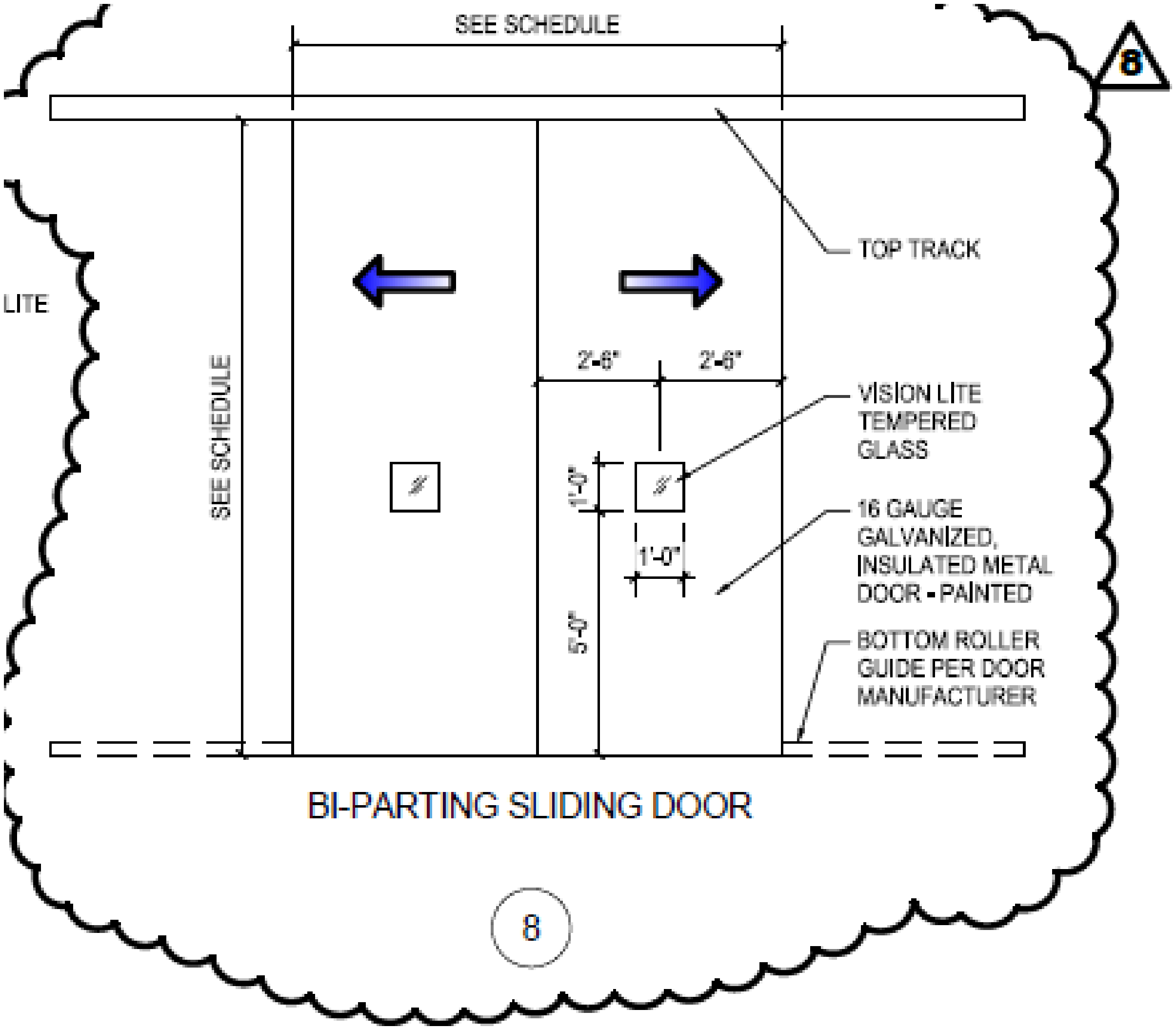
Fermilab

Docdb 5680



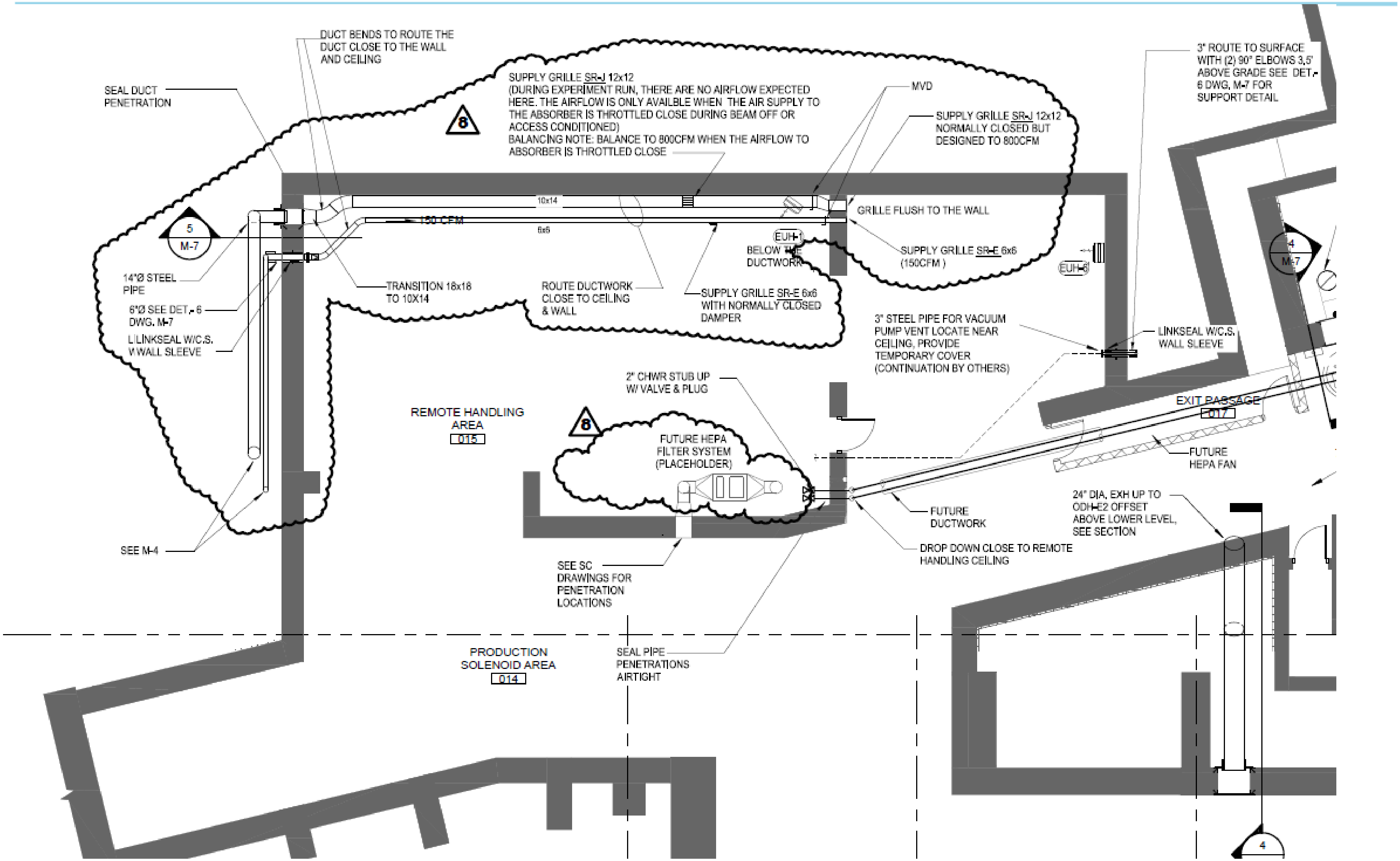
PIPE SLEEVE (TYP)
SEE MECHANICAL DWG. FOR WALL PENETRATIONS
WALLS ABOVE
B25 ABOVE
B24 ABOVE
RETAINING WALL ABOVE
B23 ABOVE
B26 ABOVE
26"Ø SONOTUBE FORM EL. 728'-7 ½
(1) 26"Ø SKEWED & (1) 8"Ø OPNG, SEE DWG, SC-14
TRANSFER GIRDERS ABOVE
T/MAT EL 720' - 6"
T/TOPPING EL 721' - 0"
N 99032.7149
E 98216.0948

Docdb 5743 v1 drawing A-28



Fermilab

Docdb 5743 v1



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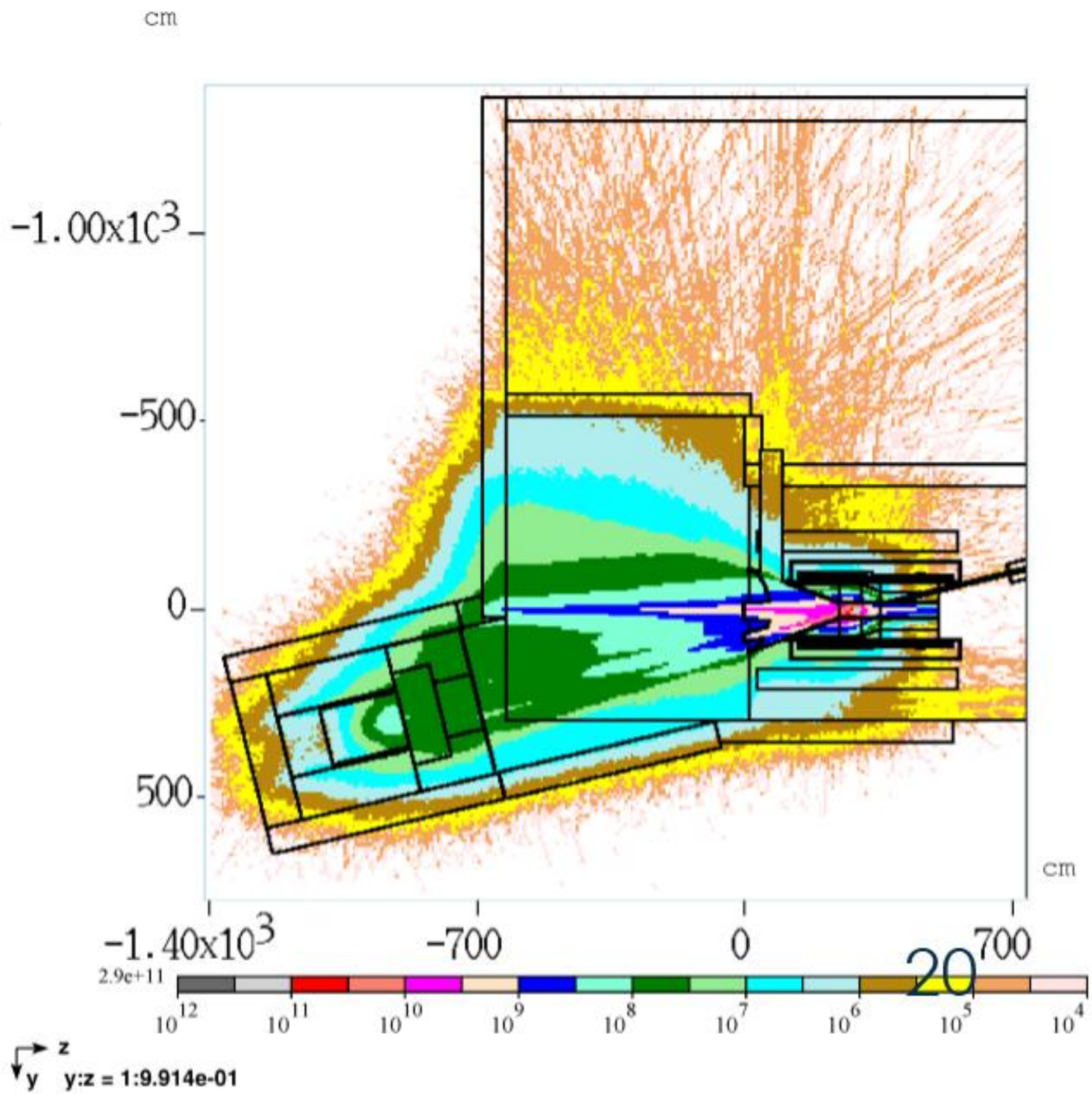
Other Possibilities to Reduce Emissions and/or Potential Contamination

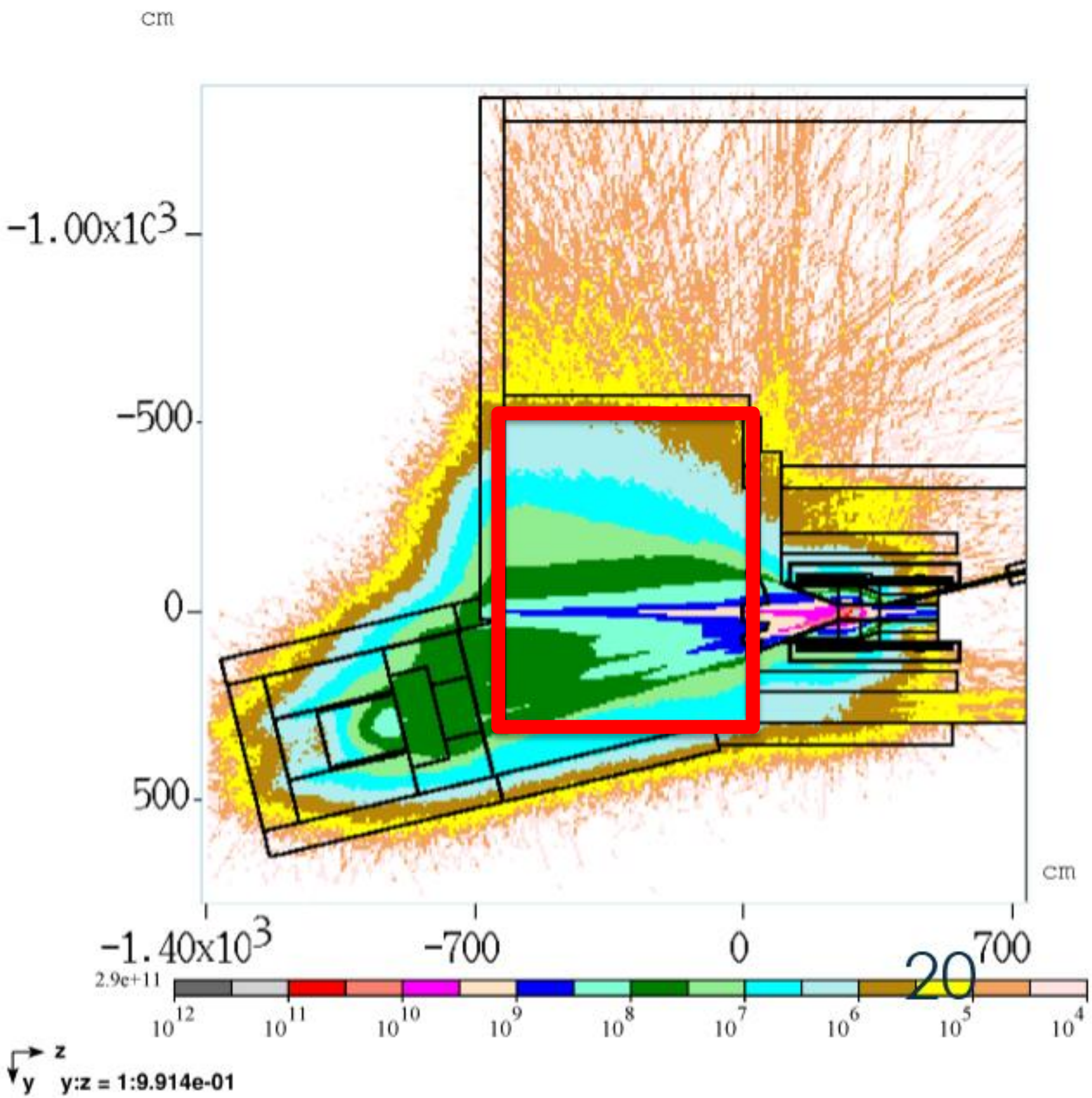
- Reduce the air temperature into the proton absorber
- Recirculate air through the proton absorber
  - And filter for ^{7}Be to minimize contamination

- Displace some of the air in the PS area since that volume is the primary contributor to activation and contamination
- Recirculate air in PS area through a HEPA filter to reduce ^{7}Be contamination levels
- Disposable floor covering to minimize contamination?

Tony Leveling Docdb 5569



- Hadron flux > 30 MeV
- 63% of the air activation activity contained in the volume outlined by the large square downstream of the PS



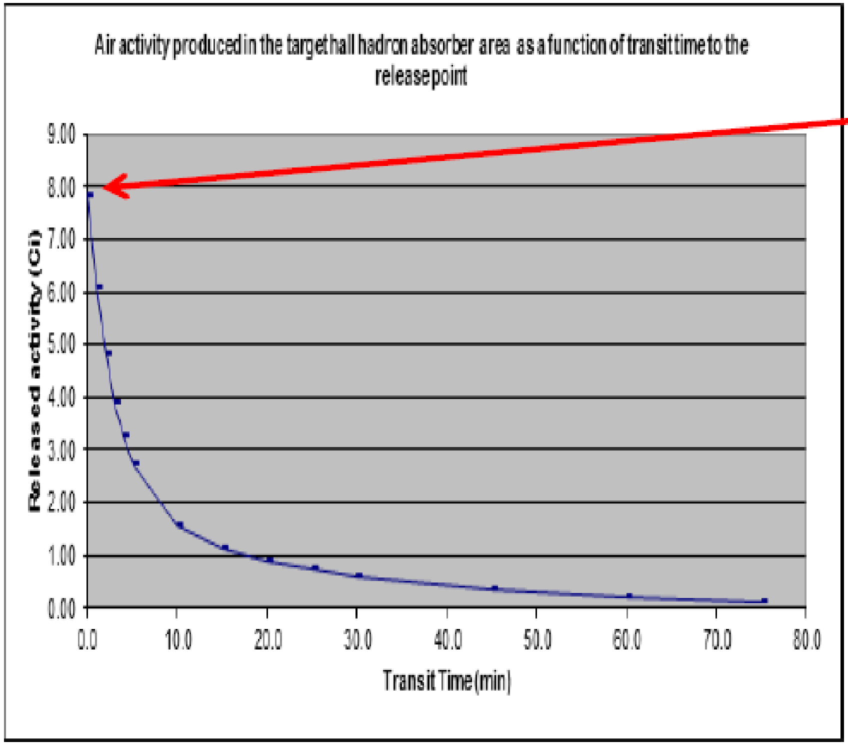
Tony Leveling Docdb 5569

- Hadron flux > 30 MeV
- 63% of the air activation activity contained in the volume outlined by the large square downstream of the PS

Fermilab

Air activity

Docdb 2460
8 kW



Kamran Vaziri

Transit time(min)	Released (Ci/yr)	
6.36E-03	7.82	At the absorber
1	6.09	
2	4.83	
3	3.91	
4	3.24	
5	2.74	
10	1.56	
15	1.15	
20	0.91	
25	0.74	
30	0.61	
45	0.35	
60	0.20	
75	0.12	
90	0.07	
120	0.03	

7.8 Ci – made in fins w/o transit time of airborne activity, (depends on vent rate and release point to outdoors distance,
21 Ci – released in the target hall.
Max 28.8 Ci a year
If assume 500 cfm of air to target hall and release near P-bar, annual activated air <21 Ci

Fermilab