Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project: MINOS / NuMI / MINERVA / COUPP / T962 and Others in MINOS Near Detector Hall.

Title: Proposed solution to the ground water cooling system fouling problem and future heat load increases in the MINOS Near Detector Hall.

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Key Words: MINOS LCW, Ground water, cooling systems, Minerva, Coupp.

Applicable Codes: none

Abstract Summary:

The ground water collected in the MINOS sump (at the base of the MINOS shaft) is used to provide cooling to the MINOS LCW system (this cools the MINOS detector magnet, power supply, and electronics racks) and the NuMI absorber intermediate skid. Refer to FESS drawing 6-7-6 PP-2 from Project 6-7-9 (The NuMI Outfitting contract) for the schematic representation of the system as originally built.

Since project completion, the ground water inflow has slowly reduced from a high of about 300 gallons per minute to the present value of about 150 gallons per minute. This measurement was made by Lee Hammond in FESS Engineering.

In addition, the sump water appears to have an increasing concentration of a slimy, rust colored material which fouls the MINOS LCW to ground water welded plate and frame heat exchanger. The presence of this material initially led to monthly heat exchanger flushing, then to the installation of a filter, and finally to the installation of a second plate and frame heat exchanger and a shell and tube heat exchanger to compensate for the fouling of the heat exchanger.

The fouling material appears to be sufficiently small that some passes thru a 50 micron filter media. Ten micron filter media appears to capture all of the material based on a visual inspection of the inner diameter of the filter cartridge.

It does not appear that the fouling has caused significant corrosion to the piping or heat exchanger. A short section of carbon steel pipe shows a complete coating of rust colored material on the inside, but no obvious corrosion evidence. See Photograph 1.

Photograph 1: Interior of carbon steel pipe formally used in the groundwater loop for MINOS.

The NuMI Absorber intermediate skid uses a large shell and tube heat exchanger between the ground water and the intermediate water loop (the intermediate water loop receives its heat from a plate and frame heat exchange with radioactive water (from the absorber core) on the hot side.

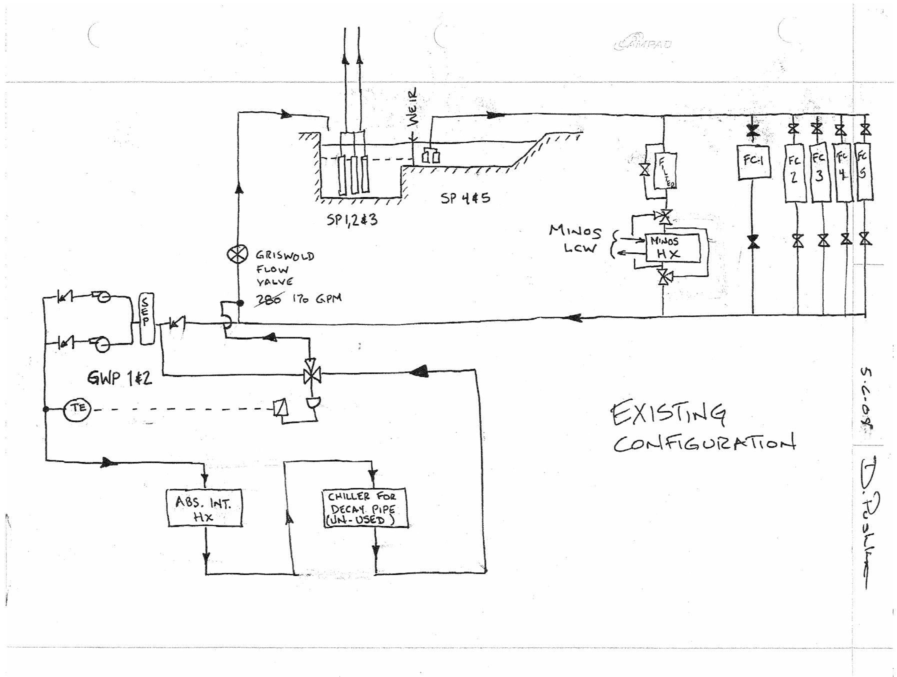


Figure 0: Present Schematic of the Ground Water System

The intermediate skid does not appear to have suffered significantly reduced performance as a result of fouling. This is likely due to the much larger flow passages in the shell and tube heat exchanger as compared to the plate and frame used on the MINOS LCW system. In addition to the decreasing water inflow, and the decreased efficiency due to fouling, the heat loads to the MINOS hall are expected to increase as MINERVA, T-962, COUPP and other experiments use the facility.

To help others understand the current configuration, a simplified sketch of the system as it exists today, is shown in Figure 0. This is largely the same as the referenced drawing 6-7-6 PP-2 from Project 6-7-9 (The NuMI Outfitting contract) but with many instruments and valves omitted for simplicity.

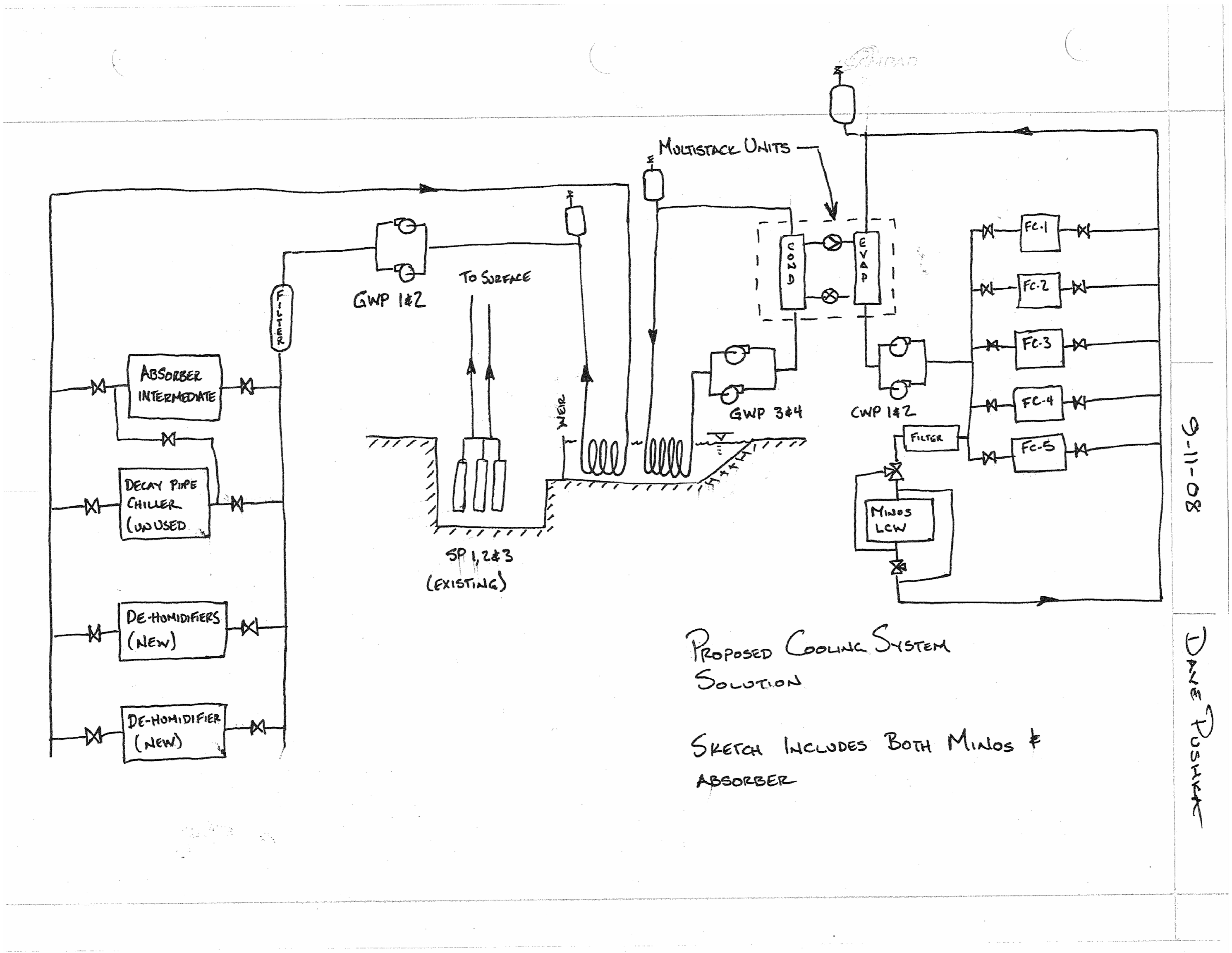


Figure 1: Schematic of Proposed Solution

Several possible system changes are possible to address the thermal load increases, the ground water flow decreases, and the fouling of the ground water side of the heat exchangers. Two alternate configurations were presented previously in engineering note number 156.

Proposed solution uses a packaged refrigerant chiller operated between two refrigerant to water heat exchangers. The cold side (the evaporator) cools a closed loop water system which in turn cools the LCW system and the fan coil (FC-1, FC2, etc.) air coolers in the MINOS hall. Once the closed loop water is warmed by the FC units and the LCW system, the same water returns to the evaporator to be re-chilled.

The condenser side of the packaged refrigerator uses another closed loop water system with heat rejecting coils submerged in the sump water. This limits potential fouling to the exterior of accessible coils.

A similar configuration of submerged coils is used to reject heat from the absorber system. Detailed calculations are included in engineering note 165.

Eliminate SP-4 and SP-5:

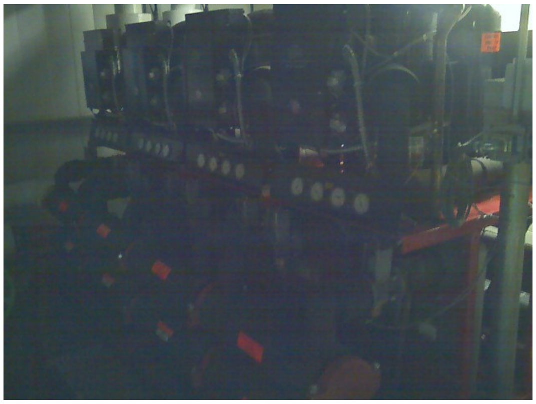
As described in engineering note 156, multiple problems have plagued the Flygt pumps SP-4 and SP-5.

Coupled ANSI style pumps are preferred by the maintenance staff because the wet end and the motor can be repaired or replaced independently. The proposed solution can use a pair of coupled ANSI pumps, mounted at floor level to replace SP-4 and 5. Sizing is to match the system curve and required flow as described in the attach calculations.

Refrigerant Based Chillers used for the Proposed Solution:

Lee Hammond of FESS has suggested using packaged refrigeration systems similar to the units that replaced the target chase chiller in NuMI. Multistack is the brand name of the unit used at MI-65. See: http://www.multistack.com/ . A photograph of the Multistack unit is shown in photograph 2 below.

One advantage of the Multistack units is that they use multiple small compressors (similar in size to the units used in large home central air conditioners). It is sensible to size the unit for the anticipated MINERVA and COUPP loads today, and plan on not operating one or two of the compressors until those heat loads appear.



Photograph 2: Multistack brand refrigerant chiller installed in MI-65

HEAT LOADS:

Heat Load Summary – Original Design Values:

MINOS LCW System	200 kW
MINOS FC-1	45 kW
MINOS FC-2	12 kW
MINOS FC-3	12 kW
MINOS FC-4	12 kW
MINOS FC-5	12 kW
NuMI Absorber	150 kW
Total:	443 kW
Total:	126 tons

One ton of refrigeration is equal to 3.5 kW.

Actual MINOS Heat Load Measurements:

The MINOS LCW system has inlet and outlet temperature differences of about 10 degrees F. At 130 gpm, this represents a heat load of 150 kW

Actual MINOS Heat Load Summary based on Measurements:

MINOS LCW System	150 kW
MINOS FC-1	45 kW
MINOS FC-2	12 kW
MINOS FC-3	12 kW
MINOS FC-4	12 kW
MINOS FC-5	12 kW
Total Existing Heat Load, in kW:	243 kW
Total Existing Heat Load, in tons of refrigeration:	69 tons

Future Anticipated Heat Load Increases:

MINERVA Electronics §	75 kW
MINERVA Magnet and Power supply §	60 kW
MINERVA Cryocooler	8.3 kW
COUPP §§	20 kW
T-962 (Argonaut)	7.5 kW
Total Additional Heat Load, in kW:	170 kW
Total Additional Heat Load, in tons of refrigeration:	44 tons

§ per MINERVA the Impact Statement dated March 12, 2004
§§ Guessed based on knowledge about the COUPP Detector

With the actual operation experience taken into account, a 70 ton refrigeration system appears to meet the present system needs. Considering the future MINERVA, COUPP, and T962 loads totaling 155 kW, an additional 44 tons of refrigeration is needed.

Thermal and Hydraulic Calculations for MINOS Chiller Solution

MINOS HALL COOLING UPGRADE USING REFRIGERANT BASED CHILLERS

	Value	Units	Comments	
Actual Heat Load Summary based on Measurements:				
MINOS LCW System	150	kW		
MINOS FC-1	45	kW		
MINOS FC-2	12	kW		
MINOS FC-3	12	kW		
MINOS FC-4	12	kW		
MINOS FC-5	12	kW		
Total:	243	kW		
Total:	69	tons	unit conversion	
Future Anticipated Heat Load Increases:				
MINERVA Electronics §	75	kW		
MINERVA Magnet and Power supply §	60	kW		
COUPP §§	20	kW		
MINERVA Cryocooler	8.3	kW		
	7.5	kW		
Total:	171	kW		
Total:	49	tons		

§ per MINERVA the Impact Statement dated March 12, 2004

§§ Guessed based on knowledge about the COUPP Detector

With the actual operation experience taken into account, an 85 ton refrigeration system appears to meet the present system needs. Considering the future MINERVA, COUPP, and T962 loads totaling 155 kW, an additional 44 tons of refrigeration is needed.

	Value	Units	Comments	
Multi-Stack Sizing for Today's Loads	69	tons		
Multi-Stack Sizing for Today's + Tomorrow's Loads	49	tons		
Total	**119**	**tons**		
Assumptions:				
Load as indicated above				
Chilled water leaves @:	50	F		10.00 'C'
Entering Condenser Water Temperature @	75	F		23.89 'C'
Chilled water returns @	60	F		15.56 'C'
Sump Pit Water Temperaure	62	F		16.67 'C'
Existing Load,	69	tons	Estimated needed Capacity	
Use three (3) MS20C4_W units	72.9	tons	Proposed Installed Capacity	
Additional Loads				
Use two (2) MS20C4_W units	48.6	tons	Proposed Installed Capacity	
Total Number of MS20C4 Units	5			
Input kW per Unit	13.7	kW	from Multistack Catalog Data	
Total Input kW	68.5	kW	Multiplied per unit input power * # of units	
Total Heat Rejected by the units, kW	493.75	kW	equals electrical energy in + load in tons coverted to kW.	
Evaporator Water Flow (gpm)	291.6	gpm	from Multistack Catalog Data	
Condenser Water flow (gpm)	338.454	gpm	use formula from multistack catalog	
Condenser Water flow (kg/s)	21.34	kg/s	unit conversion	
Cp for water	4.18	kJ/kg-K	see Appendix A, Table A.6 in Incropera and DeWitt heat transfer textbook	

Condenser Water Temperature Change	5.53	C	Calculated Delta T = q/mdotCp	
Condenser Water Temperature Change	9.95	F	unit conversion	
Entering Condenser Water Temperature @	75	F		23.89 'C'
Exiting Condenser Water Temperature	84.95	F		29.42 'C'

Evaporator Circuit Design
Assume existing 4 inch lines are used for the evaporator flows:

Evaporator Water Flow (gpm)	291.6	gpm	from above valuse taken from the multistack catalog data
Evaporator Water Flow (in3/s)	1122.66	in3/sec	unit conversion
Diameter (inner) of a 4 inch line	4.026		from Crane 410
Area of a 4 inch line	12.73	in2	calculated from A = pi/4 * d^2
Velocity in the 4 inch evaporator line	88.19	in/sec	calculated from v = Vol flow rate / Area
Velocity in the 4 inch evaporator line	7.35	ft/sec	unit conversion
Length of Evaporator Circuit	1200	feet	estimate based on length of MINOS hall
friction factor for fully turbulent, 4 inch line	0.016		initial guess
Density for water	62.4	#/ft3	
Delta P (psi) for evaporator circuit	20.804	psi	from Crane 410

Condenser Circuit Design
Assume existing 4 inch lines are used for the Condenser flows:

Condenser Water Flow (in3/s)	338.5	gpm	from above
Condenser Water Flow (in3/s)	1303.0	in3/sec	unit conversion
Diameter (inner) of a 4 inch line	4.026	inch	from Crane 410
Area of a 4 inch line	12.7	in2	calculated from A = pi/4 * d^2
Velocity in the 4 inch Condenser line	102.4	in/sec	calculated from v = Vol flow rate / Area
Velocity in the 4 inch Condenser line	8.53	ft/sec	unit conversion
Length of Condenser header Circuit	200	feet	estimated distance from unit to the sump
friction factor for fully turbulent, 4 inch line	0.018		initial guess
Density for water	62.4	#/ft3	
Delta P (psi) for Condenser header	5.2550	psi	from Crane 410
Viscosity for water @ 65 F	1	centipoise	from Crane 410
Renolds number for a Condenser header	2.65E+05		calculated, see formula in Crane 410
Friction Factor the this Re # and pipe size	0.018		see pg A-25 in Crane 410

Number of Condenser branch circuits	**15**		**initial guess**
Flow per Condenser branch circuits	22.5636	gpm	
Assume Condenser branch circuit diameter	1	inch nominal	
Diameter (inner) of branch circuit	0.995	inch	from Crane 410
Diameter (inner) of branch circuit	0.025253807	meter	unit conversion
Area of a branch circuit	0.778	in2	
Velocity in branch line as sized above	111.721	inch / second	
Velocity in branch line as sized above	9.310	ft/sec	unit conversion
Length of Condenser branch Circuit	100	feet	initial guess
friction factor for fully turbulent, 1 inch line	0.026		
Density for water	62.4	#/ft3	
Delta P (psi) for Condenser branch	18.29	psi	
Viscosity for water @ 65 F	1	centipoise	from Crane 410
Renolds number for a Condenser header	7.16E+04		
Friction Factor the this Re # and pipe size	0.026		see pg A-25 in Crane 410

External Tube Heat Transfer Coefficient
Treat as a long cylinder in cross flow

External Sump Water Flow	150	gpm	
External Sump Water Flow	20.05	ft3/second	
Channel Width	5	ft	from tunnels and halls drawing
Channel Depth	3.5	ft	from outfitting dwgs

Channel Area	17.5	sq feet	
Bulk Channel Water Velocity	1.146	feet / second	
Bulk Channel Water Velocity	0.3493	m/s	unit conversion
Area obscurred by pipe coil as described above	9.38	sq feet	
Net Channel Water Velocity	2.47	feet / second	
Net Channel Water Velocity	0.7522	m/s	unit conversion
Reynolds Number = rho*V*D/mu			
Density, rho =	997	kg/m3	
Velocity = Net Channel Water Velocity =	0.7522	m/s	
Diameter, D = Tube O.D. =	0.028575	meters	
mu = dynamic viscosity, = 1080x10-6 N-s/m2	0.00108	N-s/m2	
Reynolds Number = rho*V*D/mu	19,843	dimensional less	
Nussult Number = (h*D/k) = C*Re^m*Pr^1/3			
Constant C =	0.193		See table 7.2 in Incropera and DeWitt 2nd ed.
Constant m =	0.618		See table 7.2 in Incropera and DeWitt 2nd ed.
Prandlt Number, Pr =	7.56		for water at 290K, see appendix A, table A.6 in Incropera and DeWitt
Nussult Number, Nu =	171.5	dimensional less	
Thermal Conditivity of water, k =	0.598		for water at 290K, see appendix A, table A.6 in Incropera and DeWitt
h = Nu * k / D =	3589.5	W/m2-K	
Heat transfer calcs for Condenser branch			
Wall thickness of branch circuit	0.065	inches	value for 1 inch nominal schedule 40 pipe
Wall thickness of branch circuit	0.001649746	m	unit conversion
Thermal conductivity of Copper	375	W/m-K	value for copper, assumes not pure
Prandtl number @ 65 F (291 K)	19.3		
Colburn Equation: Nu = 0.023Re^(.8) * Pr^(1/3)			
Nussult Number, Nu d =	472.3		
Internal Convection coefficient, h = Nu * k / D	11,333	W/m2-K	
Length of Branch Circuit	100	feet	from above
Length of Branch Circuit	30.48	meters	unit conversion
Tube inner radius, R1 (meters)	0.0126365	meters	
Tube Outer Radius, R2 (meters)	0.0142875	meters	
Internal convection coefficient	11,333	W/m2-K	
Tube Wall Thermal conductivity	375	W/m-K	see above
External convection coefficient	3589.5	W/m2-K	See calculation results for the external heat transfer coefficient
Assumed Sump Pit Water Temperature	16.7	0	
Assumed Average Condenser Water Temperature	26.7	0.0	
Thermal Resistance, Tube Inner Wall	0.000036	K/W	
Thermal Resistance, Tube Wall	0.000002	K/W	
Thermal Resistance, Tube Outer Wall	0.000102	K/W	
Thermal Resistance, Total	0.000140	K/W	
Heat Transfer Rate for one Branch Tube	71.33	kW	
Number of Branches Needed	**6.92**		**calculated # of branches needed for heat transfer**

Conclusions and Equipment Sizing Summary:

Chiller Units:	5 Multistack MS20 C4 Units, Nominal 20 ton capacity chillers.
CWP 3&4:	Closed Loop Condenser Water Pumps 340 gallons per minute 30 psig differential
CWP 1 & 2	Chiller Water Pump on Evaporator 300 gallons per minute 22 psi differential
Submerged Condenser Water Loops:	1 inch nominal copper tubing (type K) 15 loops in parallel Each loop is 100 feet long.