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*Engineering for Polar Operations, Logistics, and Research (EPOLAR)*

# Waste Water Handling Proof of Concepts at McMurdo Station, Antarctica

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# Abstract

Raytheon Polar Services Company implemented two proof-of-concept waste handling methods for testing during the austral summers spanning 2010 to 2013 at Pegasus Airfield, McMurdo, Antarctica. These methods included a portable waste transfer tank and a waste incineration method. Testing and modification of these methods took place from 2010 to 2013 to determine the feasibility of long-term use of each method. Data for the actual waste water production at the runway was limited before the start of these projects and was estimated to determine proper sizing of the two methods used. During proof-of-concept testing of these methods, a more accurate determination of the waste water production was obtained as well. This is invaluable data for developing a long-term solution to handle the wastewater produced at the airfield. Both of these methods proved to be viable options dependent on the amount and type of logistical support available.

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# Preface

This study was conducted for the National Science Foundation (NSF), Division of Polar Programs, Antarctic Research Support and Logistics Program, under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ANT-12-10, "McMurdo Consolidated Airfields, Phase II: Airfield Design Guidance Continuation." The technical monitor was George Blaisdell, Chief Program Manager, NSF-PLR, U.S. Antarctic Program.

The work was performed by Terry Melendy and Dr. Robert Haehnel, (Force Projection and Sustainment Branch, Dr. Edel Cortez, Chief), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL), and Kent Colby, Raytheon Polar Services. At the time of publication, Janet Hardy was the program manager for EPOLAR. Dr. Justin Berman was Chief of the Research and Engineering Division of ERDC-CRREL. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

Our work could not have been completed without the outstanding assistance received from many Raytheon Polar Services and Lockheed Martin staff.

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COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

# Acronyms and Abbreviations

| | |
|---|---|
| CRREL | U.S. Army Cold Regions Research and Engineering Laboratory |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| ERDC | Engineer Research and Development Center |
| GII | Global Inventive Industries |
| $H_2S$ | Hydrogen Sulfide |
| n/a | Not Applicable |
| NA | Not Available |
| NO | Nitric Oxide |
| $NO_2$ | Nitrogen Dioxide |
| $NO_x$ | Nitrogen Oxides |
| $O^2$ | Oxygen |
| PEG | Pegasus Airfield |
| POC | Proof of Concept |
| RPSC | Raytheon Polar Services Company |
| SF | Safety Factor |
| $SO_2$ | Sulfur Dioxide |
| TWA | Time Weighted Average |
| UDL | Under Detection Limit |
| USAP | U.S. Antarctic Program |
| VOC | Volatile Organic Compound |
| WWTP | Waste Water Treatment Plant |

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| British thermal units (International Table) | 1,055.056 | joules |
| degrees Fahrenheit | (F-32)/1.8 | degrees Celsius |
| feet | 0.3048 | meters |
| gallons (U.S. liquid) | 3.785412 E-03 | cubic meters |
| miles (U.S. statute) | 1,609.347 | meters |
| pounds (mass) | 0.45359237 | kilograms |

# Executive Summary

Consolidation of air operations at the Pegasus Airfield, McMurdo, Antarctica, for the last part of the operational season (December–March) greatly increases the population at the airfield and, in turn, the wastewater produced there. In this study, we review several possible methods for handling black and gray water generated at the Pegasus Airfield. Of those methods reviewed, we selected two to evaluate as proof of concepts (POCs) at the airfield: on-site incineration and transportation of waste back to the waste water treatment plant (WWTP) at McMurdo Station via a vacuum tank.

After three seasons of testing both the incinerator and vacuum tank, we determined that both options were feasible though each would need to be further refined if selected for full-scale implementation. First, neither POC system was designed to handle the entire waste stream; we tested scaled-down systems at the POC stage so that together they could meet the estimated demand.

One of the important findings of this study was that not only was the quantity of waste produced at Pegasus about twice the anticipated volume but also that there was a steady upwards trend in waste production each successive season. This resulted in higher than expected labor hours and maintenance to handle the waste volume with these POC methods. Yet, with correctly sizing the waste handling systems, using the data collected in this study, and creating redundancy in the system, either of these options could be used, provided the following revisions to the systems are addressed.

Though incineration technology is attractive because it handles the waste on-site, the odor of the flue gas emitted from the evaluated incinerator was objectionable at best and by some accounts nauseated airfield staff, making it difficult to carry out their mission at the airfield. If this technology is to be used at Pegasus, further research into available commercial technologies is required to find possible solutions that could eliminate the odor of the exhaust plume.

The main limitation of the vacuum tank was finding personnel and vehicles available to move the tank and upgrading the McMurdo WWTP to accept the effluent without shocking the plant. If this method is employed, a second vacuum tank would be needed as well as a dedicated crew and prime mover allocated to handle the waste stream. Also, an equalization tank would need to be installed at the WWTP to accept the vacuum tank discharge and to allow this stream to be slowly introduced into the plant. We note that employing this method will increase the vehicle traffic on the access roads to the airfield, further increasing the load on a resource that is already distressed at the warmest times of the year.

# 1 Introduction

Historically, wastewater (both black and gray) at the McMurdo airfields has been handled by several different methods. The wastewater at the Sea Ice Runway is disposed of in the McMurdo Sound through a hole drilled in the sea ice. At Williams Field, the wastewater is disposed of through a hole drilled into the snow; as the buildings at this site are moved each season, this hole needs to be reestablished annually. The snow has a porosity of approximately 40%–60%, so the heat of the waste melts the surrounding snow into water; and in the process, the water is consolidated, making a void in the snow pack for waste disposal. Wastewater produced at the Long Distance Balloon facility was originally intended to be incinerated in the 1980s; but after some failures to the system (including catching on fire), the waste is now disposed of by dumping it into a hole beneath the snow surface as is done at Williams Field.

Before LC-130 and C-17 operations were consolidated at Pegasus Airfield (PEG), starting in 2009–10, the wastewater produced there was minimal and was handled by barreling the waste, hauling it to McMurdo Station, and shipping it to the U.S. for incineration. After consolidation, the C-17 operations meant that flights occurred 2–3 days per week, LC-130 operations included flights 6 days per week, and the limited food preparation taking place at the food hall produced limited gray wastewater. This practice of barreling waste continued during the first two years of consolidated air operations at Pegasus; the amount of waste being barreled on average for the 2009–10 and 2010–11 seasons was 445 barrels or 210,000 lb. The process of barreling the waste at the airfield consumed one full-time position during the airfield's operation and included costly transportation of waste back to the U.S.

Though the U.S. Antarctic Program (USAP) has permission to dispose of waste into the ocean, which is a very cheap option when ice cover is not relatively thick, it would be labor intensive to establish bore holes and to keep them operational for the disposal of waste through the approximately 100 ft of snow and ice located at Pegasus runway. The disposal of waste below the surface at Williams Field leaves potential waste sites that may have to be remediated in the future, which would consume program funds. Through-ice disposal is possible at the Sea Ice Runway, but this location cannot be used for more than two months each year because of the annual break out of ice on the McMurdo Sound. Additionally, with increasing awareness of environmental impacts, there is interest in moving away from disposing waste in the McMurdo Sound or in the snow and ice on the Ross Ice Shelf.

However, the disposal of waste via barreling and shipping off the continent to be incinerated is costly and not labor efficient and has demonstrated that this method should be one of last resort. Therefore, other means of waste disposal need to be explored to support PEG, especially as USAP could potentially manage waste on-site in the same manner as that being sent back to the U.S.

The objective of this study was to explore possible wastewater handling methods that can be used from November through early April at PEG. After reviewing several possible methods, we chose two to evaluate as proof-of-concept (POC) methods: on-site incineration and trucking the waste 15 miles to the McMurdo wastewater treatment plant (WWTP). In this report, we provide an overview of the methods reviewed and the rationale for selecting the POC methods. The original plan for the POCs was to be 100% in place and operational as an alternative to barreling for the 2009–10 season; both POC methods were not fully ready for use until the 2011–12 season. This report also reviews how these POC methods performed and provides recommendations for future waste handling at Pegasus Air Field.

# 2 Technology Review and Proof-of-Concept Selection

## 2.1 Background

Before considering options for waste handling, we needed an estimate of the amount of waste that will need to be handled. Initial work on this effort started by Raytheon Polar Services Company (RPSC) before air operations were consolidated at Pegasus in 2009–10. Because the operations at Pegasus and Williams Field were to be consolidated into one, we needed to obtain an initial estimate based on the history at both airfields. As previously mentioned, the waste produced at Pegasus prior to consolidation was minimal. The bulk of the waste was produced at Williams Field due to the constant air operations at that location. Unfortunately, there was no tracking of the waste generated at Williams Field since its initial construction in the 1950s. Therefore we estimated the waste produced based on the airfield crew and passengers serviced at Williams Field. Using historical data of the number of flights, of personnel at the airfield, and of passengers who passed through, RPSC estimated the waste produced at the airfield to be 13,500 gal. during the approximate 90 days of operation at Pegasus. Applying a factor of safety of 1.36 for large camps, RPSC determined a design value of 25,000 gal. (Appendix B) per season; this figure additionally included volumes of incoming waste from airplanes and people being shuttled to and from the airfield. We used this figure to design the POC methods.

To verify this design number, RPSC started monitoring waste production beginning in the 2009–10 season. Table 1 lists the black and gray water production at Pegasus over the past four seasons. By tracking the waste stream for the past four seasons, we found that the average weekly production is 2200 gal. with a peak of 3550 gal. (Table 1). The time of the peak varies between the four seasons with no systematic trend observed. The annual season production rose from 22,000 gal to more than 36,000 gal over the 4 year span. This shows that that original estimates were not as conservative as anticipated and that there has been a steady increase in waste over the last four years of operation at the airfield.

Consideration for future wastewater handling methods should take into account the increase in galley-produced gray water waste over the past four seasons. The implementation of food preparation services at Pegasus has increased by a factor of three when comparing the 2009–10 and 2012–13 seasons. This increase has also led to higher demand at the galley for potable water, which has to be transported via Delta from McMurdo Station.

Table 1. 2009–13 Annual black and gray water production at Pegasus.

| Year | Head Module (gal.) | Galley Module (gal.) | Total (gal.) | Average Per Week (gal.) | Max Week Production (gal.) |
|---|---|---|---|---|---|
| 2009–10 | 18,950 | 3,100 | 22,050 | 2205 | 2700 |
| 2010–11 | 20,150 | 2200 | 22,350 | 2235 | 2900 |
| 2011–12 | 17,240 | 7470 | 25,430 | 2119 | 3550 |
| 2012–13 | 23,470 | 12,900 | 36,370 | N/A | N/A |

## 2.2 Technology review

The following sections discuss the methods we considered for possible techniques for handling the waste water at PEG.

### 2.2.1 Direct disposal through the ice

The method of disposing solid waste through the ice shelf into the ocean has been used for many years at the Sea Ice Runway but has not been employed at Pegasus. This method is effective but is not environmentally conscientious, and the National Science Foundation would like to migrate away from future direct disposal into the environment. Furthermore, this method would not be as straight forward at PEG. The thickness of the sea ice at the Sea Ice Runway is typically about 10 ft, and pumping the waste through this hole and maintaining the hole is almost a trivial effort. Where PEG is located on the Ross Ice Shelf, the thickness of the ice is 100–150 ft. Establishing a hole, maintaining it to prevent freeze back through this much ice, and providing the means to pump the effluent down the hole against sea water and to prevent clogging of the hole due to possible freezing of the wastewater may turn this method into a large engineering effort, potentially including lining the hole and heating it to prevent it from closing. For these reasons along with the environmental impact, we deemed this a less desirable method and did not consider it further.

### 2.2.2 Storage in the ice shelf

At South Pole Station, potable water is supplied via a Rodriguez well (a rodwell) (Lunardini and Rand 1995) wherein subsurface glacial ice is melted and pumped back to the surface for treatment and use. Over time, this creates a large void or “bulb” in the ice. At the conclusion of the estimated 10-year service life of the well, the remaining void in the ice is used to dispose of wastewater. Though this method is extremely successful at South Pole Station, its application to PEG may not be straightforward as discussed in Haehnel et al. (2013). In particular, the ice shelf is relatively thin (100–150 ft) limiting the potential lifespan of the well to 2–3 years. Also, owing to the shelf ice thickness, it may be hard to contain the bulb in the ice shelf with the bottom of the bulb melting out and connecting with the salt water under the shelf. Furthermore, once the well is established and while it is being used for potable water, it needs to be monitored regularly to ensure that the bulb is maintained (i.e., it does not freeze back). This would require sending personnel out to this remote location all winter long to ensure that the well remains operable.

Once the well is no longer used for potable water, it could then be used for waste disposal. The amount of effort needed to keep the well operational would outweigh the benefits, so we did not consider using a rodwell to provide potable water and then using the void for wastewater as a potential solution at Pegasus runway.

Alternatively, a void in the ice could be established solely for the purpose of waste disposal. In this case, the bulb would be established and then the water pumped out. According to Haehnel et al. (2013), it would take about 18 days to melt out a bulb that would have a volume of 25,000 gal. The bulb would extend from a depth of about 50 to 77 ft below the ice surface and, therefore, could be contained within the ice shelf. Unresolved issues in this design include how to dispose of the water that is pumped to the ice surface—only a small fraction (e.g., 2000 gal.) could be stored and used for potable water immediately—without a detrimental effect on the airfield, over the long long-term being able to annually re-establish and locate waste bulbs close to the airfield, and designing a mobile unit for annually establishing these waste voids (Haehnel 2013). Again, this is not a trivial effort, and we did not consider this method further at this stage.

### 2.2.3 McMurdo Waste Water Treatment Plant

A WWTP already exists at McMurdo. This concept would truck the waste in a “vac tank” back to the plant in McMurdo for processing. This vac tank would be a heated tank with a vacuum unit on board that would allow pumping waste out of a holding tank at Pegasus and transporting it back to the WWTP in McMurdo—a 1000 gal. holding tank could be transported on the deck of a Delta cargo vehicle. This takes advantage of largely off-the-shelf technology and would be relatively easy to implement and to further explore as a POC. The only part that would be customized for this application would be the addition of systems to prevent the effluent from freezing in transport. Therefore, we considered this method feasible and selected it for deploying as a POC, initially fielding it during the 2011–12 season. However, before full-scale use, a plan to deal with possible spillage should be established and implemented in the event of an accident.

### 2.2.4 Incineration

Many remote camps, both military and in Antarctica (including on the South Pole Traverse), have incinerated waste. Incineration technology has improved greatly in recent years; and a few off-the-shelf solutions are available, such as from Eco Waste Solutions, who have operating units in Greenland and Canada. The most common of these are incinerating toilets that burn the waste at the time it is produced. These are suitable for small waste volumes such as at field camps. Other incinerating units store the waste in a holding tank that burns continuously once fired and are designed to handle much larger waste volumes. Because of the relative maturity of this technology, we also adopted this as a second POC for evaluation at PEG.

The incinerator system is housed in a trailer. This trailer houses four individual and independent of each other oil-fired burn units along with a 750 gal. waste holding tank. Four separate feed pumps transfer the waste from the holding tank to the individual burners. Additionally, the trailer has a separate heating system for maintaining a comfortable working environment and a ventilation system to deliver fresh air into the trailer unit.

This incinerator was initially fielded in 2010–11 with set up assistance from a manufacturer representative. However, it was returned to the manufacturer midway through the first season because of deficiencies in the initial design (described in Section 3.1.2). The unit was modified by the vender with the assistance of on-site support from the Cold Regions Research and Engineering Laboratory (CRREL) and RPSC. Once the unit was demonstrated to work satisfactorily it was shipped back to McMurdo for testing during the 2011–12 season at PEG.

#### 2.2.5 Barrel waste

As discussed previously, prior to testing the POC options at Pegasus, the procedure for handling waste at Pegasus runway was barreling all of the waste from the head modules and gray water from the dining facility and shipping it back to the U.S. for treatment. Table 2 shows the total amount of black and gray water in terms of barrels for the first two seasons of consolidated airfield operations at Pegasus and provides an estimated number of barrels for the 2011–12 season as if all of the waste had been handled by barreling.

Issues associated with barreling of waste include the additional costs of having to pay an offsite waste management company to handle the waste stream and the need to purchase and store on-site a large number of barrels each season.

Table 2. Number of barrels that would be needed to handle the waste for the first three years of consolidated air operations at Pegasus.

| Year | Head Module | Galley Module | Total Barrels | Average Per Week | Weight Per Season |
|---|---|---|---|---|---|
| 2009–10 | 379 Barrels | 62 Barrels | 441 | 44 Barrels | 207,925 lb |
| 2010–11 | 403 Barrels | 44 Barrels | 447 | 45 Barrels | 211,225 lb |
| 2011–12* | 345 Barrels | 150 Barrels | 495 | 43 Barrels | 231,375 lb |

*Estimated barrels if this method was used. However, this method was not used during the 2011–12 season.

# 3 Review of Performance of Proof of Concepts

## 3.1 Design

Two 1300 gal. holding tanks were located at Pegasus, one at the head module and one at the galley module (these also were insulated and fitted with heat tracing). RPSC did not design the two POC systems to be able to handle the full waste load for the season independent of each other. However, they had planned that they would both operate simultaneously through the season and thereby be able to meet the full demand, each handling 50% of the waste water stream. If both systems worked as planned, each would operate at less than full capacity. This created a redundancy in the system—if one or the other method failed for a short time, the load could be carried by the other system. In the event of complete failure of both systems, the fallback plan was to barrel the waste as had been done previously. These two tanks were piped together to be able to control the waste stream and to reduce potential overflow issues.

RPSC planned that the galley waste would be handled by the vac tank while the incinerator was placed next to the head module and would process the black water from the head module. The head module was plumbed directly into one of the two holding tanks and was also plumbed into the incinerator during testing, eliminating the need to transfer waste to the incinerator from the waste tank. If the incinerator needed to be taken off line, the waste from the head module would be diverted to the holding tank there and transported back to the WWTP using the vac tank.

### 3.1.1 Vacuum tank

Brown-Minneapolis Tank designed and manufactured the vac tank to transfer waste from Pegasus to the WWTP (Figure 1). As mentioned previously, the vac-tank system was designed to pump wastewater from holding tanks at Pegasus into the 1000 gal. portable transfer tank. The vac-tank package selected by RPSC included an on board engine (fueled by AN-8) that drove the pump to transfer the waste from the holding tanks at Pegasus to the tank. This same pump was used to empty the tank at the WWTP. This tank included a leak protection layer to reduce the possibility of spilling effluent during transfer or transit. The entire vac-tank system was mounted on two I-beams with fork pockets to allow easy installation and removal of the system from a Delta or trailer bed when not in use. Heat trace and a thermal blanket covered the exterior of the tank to prevent freezing of the waste during transit. The vac tank was competitively bid, and the contract was awarded to Brown-Minneapolis Tank. The anticipated maintenance was expected to be minimal. RPSC and CRREL determined that, in an effort to reduce potential maintenance and vehicle down time, the POC should be removable from the prime mover that it was attached to. If this form of waste management was to be implemented full time, a dedicated prime mover would be the viable option. The recommendations section of this report provides more details on this.

Figure 1. Vacuum tank as it arrived from manufacturer.

As delivered, there was no onboard capability to power the heat trace, and insufficient capacity was available on the Delta that was used during the 2011–12 season. During the 2012–13 season, Lockheed Martin added a generator to the package to power the heating system during transport.

At the WWTP, the contents of the tank were discharged into the waste stream after the flow weir, limiting the impact on the plant. Additional piping had to be added at the plant to allow transfer of this source of waste into the plant. The treatment plant experienced operation issues with the addition of waste from Pegasus as explained in detail in the *2011–12 McMurdo Station Wastewater Treatment Plant End of Season Report*, written by Yubecca Bragg, wastewater treatment plant operator (Bragg 2011, 2012). These issues included low biochemical oxygen demand, nitrogen ammonia, phosphorus, and total suspended solids of the Pegasus wastewater exceeding the parameters of the plant design. A report produced by Martin and Martin Inc. on the wastewater treatment plant efficiency in December of 2012 determined that the waste being produced at Pegasus and sitting stationary before being transported to the treatment plant had ample time to become septic, resulting in the issues documented by the wastewater treatment plant operator (O.Z. and Martin and Martin Inc. 2013)

It was expected that the transfer trip would need to be completed 2–3 times per week to keep up with galley wastewater production. Each round-trip was expected to take up to 4 hr. The actual amount of trips that needed to be completed for the 2012–13 season on a weekly basis was 4–5.

### 3.1.2 Incinerator

The requirements of the incinerator were as follows: is self contained; is portable; is capable of burning 300 gal. of black water waste in a 24 hr period, producing only 1 cup of white ash after 300 gal.; is capable of burning on AN-8 fuel at a rate of 0.7 gal. per burn hour; has a secondary heat source included for freeze protection; has motorized air duct to provide fresh air; has the capability to shut down the waste burning units individually; and has an alarm system to signal when issues arise with the burners. The required capability of processing 300 gal. of black water per day allowed as much as 15,000 gal. to be processed each season by this method. Requirements for maintenance were not specified and only designated to not be extreme. Global Inventive Industries (GII) was selected, based on competitive bid, to provide the portable incinerator system.

The tested incinerator handled wastewater as follows. Waste was transferred directly from the head module to a 750 gal. plastic holding tank within the incinerator enclosure. Within the enclosure, there were four independent burners that were each controlled individually via independent control boards located on each unit. There were four individual pumps that pumped the waste from the holding tank to burn trays in each individual burn unit's combustion chamber. The diaphragm pumps were not positive displacement types, so the amount of waste deposited into each tray for a burn cycle was controlled by the duration of the pump operation time. The operation times of these pumps were set by the manufacturer and had the capability to be modified by the on-site operators. Once the waste was transferred to the burn trays, the burners ignited and ran until the stack temperature exceeded a preset "high" temperature limit (850°F). When properly set, all of the waste in the tray was burned off in the burn cycle.

The burners were in a horizontal orientation that produced a flame at the front of the tray with the expectation that the heat would be distributed over the entire tray. The exhaust and steam produced exited the four burning units through four independent, double-walled exhaust stacks. The approximate temperature at which the waste was burned in the chamber was around 900°F.

GII typically uses propane burners in their other models. For this application, the specification required use of AN-8 for the fuel, which can be burned in standard fuel oil burners. The reason for this change was because AN-8 is used routinely at Pegasus; propane is not available at McMurdo and is not a suitable fuel for use in the low temperatures regularly seen at McMurdo.

The incinerator was first fielded at PEG during the 2010–11 season (Figure 2). After initial operation, we quickly identified several deficiencies with the system, as discussed in Section 2, and deemed the unit as not performing to specifications. We returned the unit to the manufacturer for revision and tested the updated incinerator unit during the 2011–12 season.

Figure 2. Incinerator and wastewater set up at Pegasus Runway, 2011–12.

## 3.2 Field evaluation

### 3.2.1 Vacuum tank

The vac tank that arrived at McMurdo during the 2011–12 season had to be modified immediately after arrival to ensure the safety of personnel and to limit snow drifting into the engine compartment. Modifications to the system included the addition of a platform with guardrails (as shown in Figure 3) because the Delta transporting it would put the unit approximately 6 ft off of the ground; the railing helped to prevent personnel from falling off of the Delta bed while operating the vac tank. Figure 4 shows the vac tank installed on the back of the Delta.

Figure 3. The vacuum tank as delivered (left) and after modification (right).


Figure 4. Delta with the vacuum tank.

We also discovered that drifting snow could easily infiltrate the engine compartment. To reduce snow ingestion into the engine compartment, we insulated the enclosure.

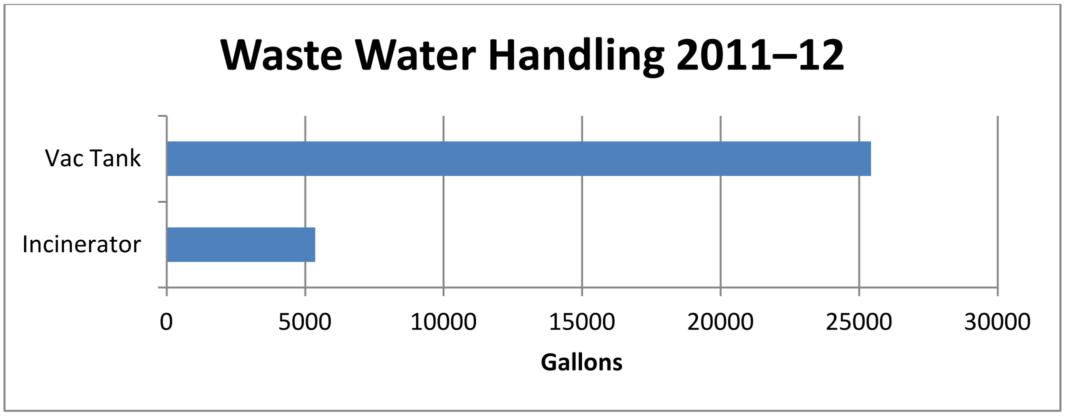
Another limitation that we immediately identified was that the 1000 gal. transfer tank could be filled to a maximum of only 750 gal. for safe transportation. This increased the potential for having to make more trips to keep up with the waste stream. The vac system was successful at handling the waste stream from Pegasus with the increased personnel and a prime mover dedicated to waste transfer for a minimum of 4 days a week. However, more waste than expected was produced; and along with limited holding capacity at Pegasus, this led to more frequent transfer trips.

Further complications arose when dumping the high solid concentration waste stream into the treatment plant. If the effluent was unloaded too quickly at the WWTP, it shocked the system. To avoid shocking the WWTP, the tank needed to drain slowly over several hours, increasing the round-trip time. This also increased the time the Delta was tied up with waste transfers as the fully loaded vac tank is too heavy to be offloaded by most forklifts on station. This delayed how soon the Delta could resume cargo transfer operations, creating potential backlog in cargo transfers. If the unit could have been offloaded from the prime mover, it would have aided in reducing the shock on the WWTP by acting as a small storage tank that could slowly disperse the waste from the runway over 12 hr in comparison to unloading in 1–2 hr. Because of the yearly increases in waste water production, we are uncertain if this type of waste unloading would have been enough to reduce the need for a surge tank or a dedicated prime mover. If the waste stream from the runway is increased, the vac tank would have to operate more frequently and may require more than one trip per day, preventing it from acting as a temporary holding tank at the WWTP.

Other issues with the transfer tank included the malfunction of the heat tape installed along the transfer tank. This lead to the waste dropping in temperature along the transfer route and required a waste operator to accompany the Delta operator to monitor freezing within the tank and to ensure the safety of the waste transfer.

Despite these difficulties, this POC test demonstrated that the vac tank is a viable option for handling the waste stream produced at Pegasus; but to be a long-term solution, it will require additional logistical support. This includes increasing its capacity. A total of 20,068 gal. of waste was transported from Pegasus back to the WWTP during the 2011–12 season. Figure 5 shows a comparison between incineration and waste transport. It is possible to have larger vac tanks used for waste transfer to reduce the amount of trips; but it is unclear if the bearing capacity of the snow roads would be able to support that, especially in the warm part of the season. Therefore, it may make more sense to have two tank systems with dedicated prime movers for waste transport. The vac tank in its current configuration is a single point of failure system, meaning that if a prime mover cannot be secured or if the vac tank fails, there is no back up transfer system other than barreling waste. This further supports the recommendation to increase capacity by providing two identical systems that can be transported on a variety of platforms. Furthermore, to continue using a waste transfer system, an equalization tank will need to be installed at the WWTP to help regulate the concentrations of waste when the vac tank is unloaded quickly to allow the prime mover to be made available for other tasks.

Figure 5. Waste water handling distribution for the 2011–12 season.




At this time, waste personnel on station are looking into regulations to determine if a licensed waste operator will be required to accompany the vac tank for safety reasons. This requirement was not known at the time of implementation of this POC.

Owing to the success of this method for waste handling, it was used at Pegasus during the 2012–13 field season to handle all of the waste produced there.

### 3.2.2 Incinerator

The incinerator unit (Figure 6) first arrived at McMurdo station during the 2010–11 season. During the four weeks of testing performed by the contractor and vendor, CRREL noted multiple issues:

1. The burner overheated, causing the burners to shut off mid-cycle.
2. The tray overfilling, caused by double drawing of waste from the pumps and overfilling of the burning trays (Figure 7), resulted in black water saturating the burn chambers and spilling out onto the floor
3. Control panel wiring was different for each of the four burners, making it difficult to trouble shoot.
4. The tray life was less than manufacturer expectations of 300 hr. The actual life span was measured at approximately 75 hr each.
5. The space heater had problems operating.
6. The fork lift pockets were not installed.

7. The four burners would not run for equal amounts of time during cycles, resulting in higher maintenance schedules on two of the burners when compared to the others.

These problems resulted in the incinerator not performing up to specifications and required a lot of additional attention to keep it operating. During this test period, the average amount of black water processed during the 24 hr test periods was 171 gal. while the specification required processing of 300 gal. of waste in a 24 hr period.

Figure 6. Incinerator at the manufacturer's facility, California.

Figure 7. Tray overfilled, causing effluent to spill out of the tray (left) into the exhaust plenum and to leak out of the burner unit onto the floor, saturating the combustion chamber insulation with black water (right).

Also, during the 2010–11 season, the unit started to settle and was no longer level. This resulted in the effluent not being evenly dispersed in the burn trays and caused higher than expected caking on the back of the trays. This lead to more frequent maintenance intervals on the trays, going from the expected maintenance interval of 300 hr to once every 75 hr of run time. This underscored the importance of making sure the incinerator unit was installed and maintained level.

After the four-week testing period, the incinerator was sent back to the U.S. to resolve the problems listed above.

During July–October 2011, CRREL and RPSC representatives worked with the manufacturer to resolve the identified operational issues. Modifications included changing all four feed pumps to a more robust style pump (positive displacement style pump), upgrading the control panels on each burn unit (so they could be adjusted individually), installing fork pockets, making wiring upgrades within the incinerator unit (standardizing the wiring in each unit, making maintenance easier), installing warning devices that would detect early signs of waste spills and shut down the unit, calibrating the four burner units to operate on similar run times during cycles, and evaluating the effectiveness of the catalytic converters.

Furthermore, the burn trays were originally aluminum; but during the 2010–11 tests, we concluded that the trays did not hold up well to the hotter flame produced by AN-8 combustion (compared to that of propane), leading to premature failure of the aluminum trays. We replaced the aluminum trays with cast iron trays that had additional fins added to the design to create a more even heat distribution on the tray. These trays were reversible, which improved the life as well. These new trays were included as part of the upgrades, also.

In addition to the upgrades mentioned above and shown in Figure 8, tray viewports were added to each of the four burn units to allow staff to visually inspect the amount of waste being pumped into each tray without having to climb up on top of the incinerator and view the trays through the exhaust stacks.

Figure 8. Four burner chambers inside the incinerator and control panels that were upgraded (left) and waste water storage tank with upgraded piping and feed pumps (right).

Once the modifications were completed, verification tests were conducted at the manufacturer's facility in Riverside, CA, to ensure the unit was meeting performance specifications, including the ability to shut off the burners if issues were detected; this included tray overfill. Testing consisted of burning black water for 20–24 hr each day for 3–4 days to ensure the incinerator would process 300 gal. of black water in a 24 hr period. This was successfully accomplished during an on-site visit in October of 2011. At the end of the two on-site evaluations, we determined that the incinerator was operational; and it was shipped back to McMurdo Station, Antarctica, for full POC testing during the 2011–12 season.

The unit returned to McMurdo in November of 2011 and was used successfully over an 8-week period from December 2011 to February 2012, burning at a rate comparable to 300 gal. of waste water burned in a 24 hr period. During this time, the most prominent issue identified was the odor of the exhaust gas, which was described as a heavy metallic fragrance. Though CRREL and RPSC noted the odor during testing at the factory, the team evaluating the performance of the incinerator did not consider it overpowering. However, in the Antarctic environment, the smell was considered overpowering by many who had to work in proximity to the incinerator. To ameliorate this issue during the POC tests, we operated the incinerator at off peak hours to help accommodate the personnel on-site. This limited the operation time to 8 hr per day instead of the planned 20–

24 hr shifts as done in 2010–11. These reduced operation hours decreased the amount of waste that the incinerator could process.

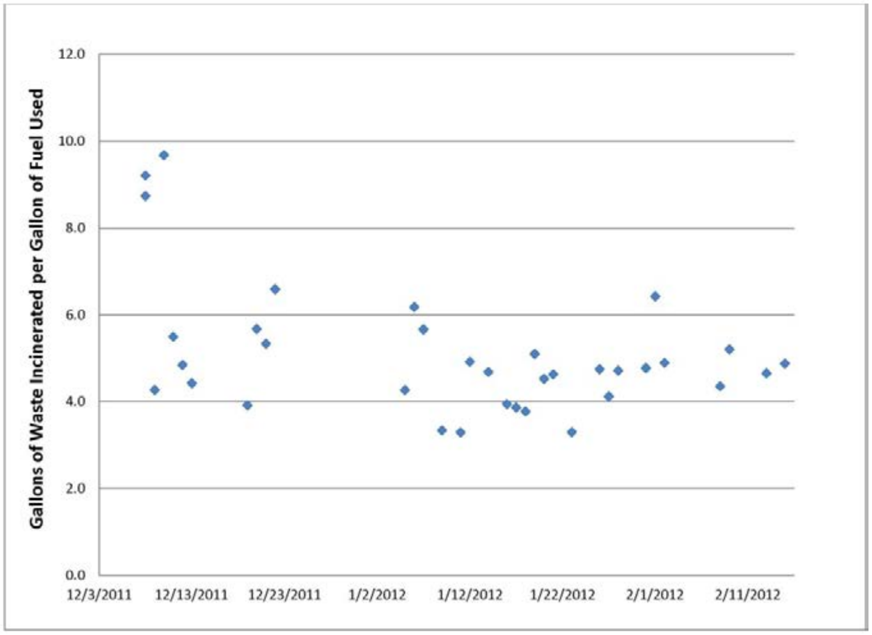
The total amount of waste incinerated during the test period was 5362 gal. If operated 20–24 hr per day during this same timeframe, this unit could have incinerated 15,000 gal. By burning 5362 gal. of waste, this reduced the vac tank's load by 7 trips; and if barreled, this would have equated to one hundred and seven 55 gal. drums that would have needed to be transported back to McMurdo for ship loading. If the incinerator had been operated to the designed specifications of 20 hr a day, the number of vac-tank trips could have been reduced to 21.

During operation, we observed that the fuel used to incinerate a given amount of waste water was higher than what was achieved at the factory: for every gallon of AN-8 consumed, an average of 5.7 gal. of waste was burned. Figure 9 shows the scatter in this data. At the factory, we observed that the average amount of diesel fuel consumed during the 24 hr test periods was at a ratio of 11 gal. of waste incinerated for each gallon of diesel* fuel consumed by the burners (note, this did not include fuel consumed for operation of the oil-fired space heater). The reason for the lower than expected processing efficiency is most likely attributed to the amount of times the furnace turned on to prevent freezing of the incinerator. While the heat produced from the four burners operating at the same time resulted in temperatures over 100°F inside of the incinerator unit, because the incinerator operated only 8 hr per day rather than 20–24 hr, the heater likely was used more than what was originally planned. However, furnace use was not tracked, so we do not know the extent to which this was a contributing factor. The low conversion efficient may also have been influenced by the lower external temperatures, causing the burners to operate longer to reach the upper temperature limit. Also, the percent solids in the waste being burned at Pegasus was considerably higher than typical black water waste found in the U.S., which would require modifications to the pump cycles and longer burning times to reduce the amount of caking on the trays. Another factor could be the use of AN-8 fuel at McMurdo instead of standard diesel fuel, though the heating values of the two fuels is com-

* Diesel was used for all of the tests conducted at the factory as it is readily available and is very similar to AN-8. The fundamental difference is AN-8 is formulated for operation in cold temperatures (down to −50°F) while diesel is not.

parable (123 MBTU/gal. for AN-8 vs. 128 MBTU/gal. for diesel); and this is likely not a large contributor to the reduction in conversion efficiency.

Figure 9. Incinerator conversion efficiency.




The new burner trays made of cast iron proved to be more reliable and longer lasting than the aluminum ones used the season before. However, an issue that was not visible during testing in California was the increased caking on the trays as shown in Figure 10. This lead to increased tray maintenance to remove the buildup but did not affect the tray's life expectancy. We noted that the caking was reduced somewhat by increasing the burn temperatures in the combustion chamber. However, extended service at these higher temperatures is expected to reduce the tray life.

Figure 10. Cast iron tray before installation at McMurdo (left) and after normal usage during the 2011–12 season (right); note the visible caking on the tray on the right.

As stated previously, the odor produced by the incinerator was a major obstacle to achieving full use of this method. Two differences between operations at the factory and at McMurdo were the fuel used, diesel vs. AN-8, and the percent of solids in the waste stream due to the waterless toilets at Pegasus. To explore the possibility that either of these affected the odor, we tested both fuel types in the incinerator during the 2012–13 season along with varying levels of dilution (0% and 25%) of waste and implementing aeration (Figure 11). Listed below is the test plan designed by CRREL and carried out by the contractor during December of 2012.

1. De-winterize and prepare the incinerator to operate with AN-8 fuel.
2. Install turbulence aerator with pre-fabricated mounting piece. (2 × 6s).
3. Run multiple cycles in the initial testing and confirm the proper operation of the incinerator based on the prior year's performance with the addition of the aerator for the 2012 season.
    a. Testing should consist of 6–10 hr of burning and noting the smell and performance.
4. Dilute waste with 25% melt water in the holding tank and test the incinerator.
    a. Testing should consist of 6–10 hr of burning and noting the smell and performance (burn rate and caking). Repeat this at least 2 times using the aerator and AN-8 fuel.
5. Assemble fuel insulation box over the incinerator fuel tank and pour in 100 gal. of diesel from on-site and operate the incinerator with the aerator. (It should be noted that adjustments to the 4 individual burners located within the incinerator may need to be made to accommodate burning with diesel.)
    a. Operate the incinerator, as previously completed for the AN-8 fuel, for a 6–10 hr period or approximately 125 gal. of waste with the straight diesel fuel, non-diluted waste, and aerator running.
    b. At the end of the test period, the operator should document if there is a change in smell in comparison to the operation with AN-8 fuel.
    c. Dilute the waste mix with 25% water. Operation should continue with aerator and diesel for another 6–10 hr period or approximately 125 gal. of waste removal, and document the smell at that time during the test. Documenting other individual's interpretation of any smell change is suggested as well.
    d. Continue testing with the diesel fuel, adjusting firing temperatures, burners, and flow rates as needed. (This should be determined by the

operator of the incinerator.) Document any change in smell or performance.

6. Operate the incinerator with undiluted waste using AN-8 and the aerator. Document changes in performance and smell. This is the same test as completed in step #3. The purpose is to double check that the smell has not changed from original state.

Figure 11. Incinerator holding tank aerator.

Results documented in *Global Inventive Industries 720S Incinerator* (Bragg 2013) by Antarctic Support Contract personnel stated that the implementation of the aeration system (Figure 11) resulted in a less metallic smell. Changing the fuel type did not affect the smell; however, the burners were not adjusted for the fuel type, creating a light brown smoke from the stacks when burning diesel vs. a white smoke from the AN-8. Diluting the waste stream did not have an effect on the smell. It should be noted that because of the lack of non-objective “smelling” techniques, it was up to the operator’s discretion to determine the change in smell when the incinerator was operating.

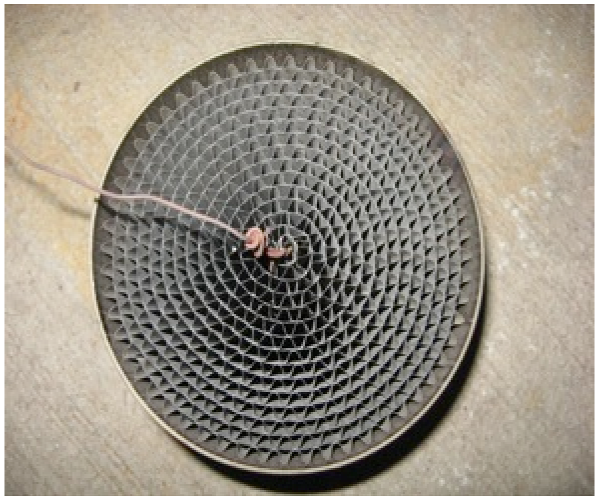
In an effort to understand the source of the odor and thereby possible methods to reduce it, we conducted emissions testing (Figure 12) both at the factory and in the field. Appendix A provides a summary of those test results. Based on these findings it appears that sulfur dioxide could be the main source of the odor as it was the only compound detected that was above its odor threshold. Unfortunately, because of testing services available, the test methods used did not detect all possible compounds. For example, hydrogen sulfide—which produces a “rotten egg” smell—was not tested for, and that may also have been a contributor to the odor. Fortunately, both of these compounds can be removed from the flue gases using scrubber technology. We recommend that future tests of the incinerator employ stack scrubbers to determine the viability of using that technology to reduce the odor associated with incinerator emissions.

Figure 12. Emissions testing of the incinerator at Pegasus Airfield.

Another method that may be employed to reduce odor is increasing the incineration temperature. The incinerator tested in this study has an incinerating temperature of approximately 900°F. Other incineration systems operate at approximately 1400°F. There is no reported odor for these other high-temperature incinerators, suggesting that the higher temperatures promote complete combustion of the effluent, thereby eliminating partially burned compounds such as hydrogen sulfide, and possibly reducing odor. Note that higher combustion temperatures would not eliminate dioxide emissions as this is a product of complete combustion of sulfur compounds.

Also, discussed in Appendix A, we found that though the catalytic converter (Figure 13) reduced carbon monoxide (CO) emissions, it was ineffective at reducing other exhaust emissions. We note that the CO emissions at the stack exit without the catalytic converter installed were above the time weighted average exposure level of 35 ppm as outlined by the U.S. Environmental Protection agency. It is uncertain as to whether the CO levels at ground level are within acceptable levels; therefore, we recommend that, if possible, the incinerator be operated with the catalytic converter installed. Unfortunately, when properly installed, these created backpressure on the combustion chamber; and since the combustion chambers were not air tight, the emissions were pushed out of the burner units and into the trailer, creating a health hazard for the operators. As a result, major revisions to the burner units would be required to seal the chamber so that it could operate with the converters installed.

Figure 13. Catalytic converter.



### 3.2.3 Other considerations

We note that other problems were encountered while implementing these POC methods. For example, the head module was susceptible to waste backups from the exit piping. This was experienced during the 2011–12 season because the piping to the holding tank became plugged and resulted in waste running onto the floors. An onboard waste tank located under the head module could potentially reduce the occurrence of this issue and should be considered in future generations of the bathroom facilities.

# 4 Conclusions and Recommendations

By the end of the 2011–12 summer season, both waste POCs, incineration and transportation by vac tank to the McMurdo WWTP, were operational; and when used together, they were capable of handling 100% of the wastewater created at Pegasus. This resulted in no wastewater being barreled and shipped back to the U.S. for treatment. This marked the first time at Pegasus where waste was disposed of on-site or on station.

Though the POC tests demonstrated that either method will work, neither is properly sized to handle all of the waste produced at PEG; and revised designs would need to be implemented for long-term waste management. With expected food preparation to increase at the Pegasus dining facility, increased waste production is expected in the near future, which will increase the required capacity of either of these systems. We recommend that current waste water tracking methods continue to track trends for future solutions.

Furthermore, these tests showed that each of these systems will need modifications to address shortcomings identified in this effort. For the vac tank, these modifications are the following:

1. Increase storage space at Pegasus for holding waste before transport (larger storage tanks).
2. Add an equalization tank at the WWTP to allow rapid unloading of the effluent at the plant.
3. Provide a dedicated prime mover to support waste transfers.

For the incinerator we recommend the following:

1. Resolve the odor problem or reduce it to acceptable levels (a review of emissions suggests that implementing stack scrubbers may resolve the odor by removing sulfur compounds from the emissions).
2. Revise the combustion chamber design to use the catalytic converter to bring CO emissions within acceptable levels.
3. Explore other incineration technologies that use higher combustion temperatures, thereby reducing the odor and the amount of unburned effluent (caking).

Incineration is currently being used around the world in cold, remote locations such as in Canada, Greenland, and Alaska. Companies with long track records of successful design and implementation of systems do exist and should be looked into for future waste handling methods. Additional advantages that these advanced systems have is the ability to use waste heat (from the stacks) to provide heat for other operations, such as melting snow. Owing to the fact that some of these systems operate at higher combustions temperatures, odor is reported as not being an issue.

Furthermore, the final system has to contain redundancies to make sure there is no single point of failure. This may mean redundant components in the system (i.e., multiple identical vac tanks or extra burner capacity) or multi-mode capability (as was done in this study) such that, in the event of a short-term failure in one system, the burden can be carried by the other system. The amount of time required for the barreling process of waste water and removal is significant and should only be used as a last resort.

We note that during this study, another issue was encountered. The plumbing from the head module to the holding tanks became plugged, causing back-up of the waste into the heat module. Addition of an onboard waste tank located under the head module could potentially reduce back-up of the waste in the head module and should be considered in future generations of the bathroom facilities.

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# Appendix A: Incinerator Emissions Analysis

## Background

During the evaluation and testing of the waste incinerator at the manufacturing facility in Riverside, CA, and at the Pegasus Airfield (PEG) spanning the 2011–12 Austral summer season, some measurements of the incinerator flue gas were obtained to determine the emission composition; concentration of constituents; effectiveness of the catalytic converter; and possible source of the odor, thereby identifying possible means to reduce or eliminate the smell. Initial testing was conducted with a portable combustion analyzer that allowed near real-time determination of a limited number of exhaust gas components: oxygen ($O_2$), nitric oxide (NO), nitrogen oxides (NO and $NO_2$ [nitrogen dioxide], generically referred to as $NO_x$), sulfur dioxide ($SO_2$), carbon dioxide ($CO_2$), and carbon monoxide (CO). This evaluation was conducted at the plant in Riverside, CA. Because only a limited number of possible compounds could be detected with the combustion analyzer, a second evaluation of the exhaust gas emissions to determine the volatile organic compounds (VOCs) in the emissions was conducted at PEG during POC testing of the incinerator. What follows is a summary of the findings from these two sets of emissions tests and recommendations for a possible way to resolve the odor issue.

## Portable combustion analyzer

Initial emission testing was conducted during incinerator evaluation at the manufacturing facility in California (July 2011) using a TSI CA-Calc 6213 Portable Combustion Analyzer. In this case, the wand of the analyzer was placed directly in the flue gas emitted from the top of each of the 4 stacks. The evaluation was done both with and without the catalytic converter installed. Table A1 provides a summary of the results of this initial evaluation. The concentrations listed are an average of the readings taken at each of the 4 stacks.

In Table A1, we have also listed the odor associated with each. The odor information was obtained from material safety data sheets for each of the components. Of these, $O_2$, NO, $N0_x$, $CO_2$, and CO are odorless. Sulfur dioxide, however, has a strong odor like "struck matches" as noted in Table A1.

Table A1 shows that with the catalytic converter installed, the carbon monoxide levels are also below acceptable exposure limits. The catalytic converter provided by the manufacturer seems to have no effect on reducing emission concentrations for the other measured components: NO, $NO_2$ and $SO_2$.

Table A1. Summary of emissions measurements obtained July 2011. Diesel fuel was used for running the burners in this case.

| | Average Concentration* | | Odor | |
|---|---|---|---|---|
| Compound | Catalytic Converter installed | No Converter | Threshold (ppb) | Odor |
| Oxygen | 6.3% | 8.3% | n/a | Odorless |
| Carbon Monoxide | 22 ppm | 129 ppm | n/a | Odorless |
| Nitric Oxide | 150 ppm | 120 ppm | n/a | Odorless |
| Nitrogen Dioxide | 7 ppm† | 7 ppm† | n/a | Odorless |
| Sulfur Dioxide | 24 ppm | 24 ppm | NA | Match strike |
| Carbon Dioxide | 0% | 0% | n/a | Odorless |

n/a: not applicable

NA: not available

* Measurement averaged across readings obtained for each of the 4 exit stacks.

† Determined by subtracting the measured NO levels from the measured $NO_x$ concentration.

The description of the odor associated with sulfur dioxide (Table A1) is consistent with the smell observed during evaluation of the incinerator in Riverside, CA, and with some accounts given for the odor observed during incinerator operations at PEG.

## Volatile organic compounds

To determine the presence of VOCs, three flue gas samples were collected. Table A2 lists the VOCs tested for. Two samples were collected on 11 February 2012; these samples were collected on top of the incinerator, as shown in Figure A1, not next to the stack exit. Therefore, we expect that these samples would be somewhat dilute and may not represent the emissions in the main exhaust plume. The third sample was collected on 14 February 2012. In this case, a lift truck was used to place the sampler directly in the exhaust plume as shown in Figure A2; this sample is a composite of the exhaust coming from all 4 flue pipes. Consequently, we expect the sample taken on 14 February to be of higher concentration and *more* representative of the maximum concentration of VOCs in comparison to the other tests performed.

Table A2. Alphabetical listing of all of the VOCs tested for during the emissions analysis conducted by Hill Labs.

| | | |
|---|---|---|
| 1,1,1,2-Tetrachloroethane | Acrylonitrile | Cumene (Isopropylbenzene) |
| 1,1,1-Trichloroethane | Allyl chloride | Methyl methacrylate |
| 1,1,2,2-Tetrachloroethane | Benzene | Methyl *tert*-butyl ether |
| 1,1,2-Trichloroethane | Benzyl chloride | Methylene chloride |
| 1,1-Dichloroethane | Bromodichloromethane | Naphthalene |
| 1,1-Dichloroethene | Bromoethene | *n*-Butylbenzene |
| 1,2,4-Trichlorobenzene | Bromoform | *n*-Propylbenzene |
| 1,2,4-Trimethylbenzene | Bromomethane | *o*-Xylene |
| 1,2-Dibromoethane | Carbon disulfide | *m,p*-Xylene |
| 1,2-Dichlorobenzene | Carbon tetrachloride | Cymene (2-Isopropyltoluene) |
| 1,2-Dichloroethane | Chlorobenzene | Propene |
| 1,2-Dichloropropane | Chloroethane | *sec*-Butylbenzene |
| 1,3,5-Trimethylbenzene | Chloroform | Styrene |
| 1,3-Butadiene | Chloromethane | *tert*-Amyl methyl ether |
| 1,3-Dichlorobenzene | *cis*-1,2-Dichloroethene | *tert*-Butyl alcohol |
| 1,4-Dichlorobenzene | *cis*-1,3-Dichloropropene | *tert*-Butylbenzene |
| 1,4-Dioxane | Cyclohexane | Tetrachloroethene |
| 2,2,4-Trimethylpentane | Dibromochloromethane | Tetrahydrofuran |
| 2-Butanone | Dichlorodifluoromethane | Toluene |
| 2-Chloroprene | Dichlorotetrafluoroethane | *trans*-1,2-Dichloroethene |
| 2-Chlorotoluene | Diisopropyl ether | *trans*-1,3-Dichloropropene |
| 2-Hexanone | Ethyl acetate | Trichloroethene |
| 4-Ethyltoluene | Ethylbenzene | Trichlorofluoromethane |
| 4-Methyl-2-pentanone | Ethyl *tert*-butyl ether | Trichlorotrifluoroethane |
| Acetone | Heptane | Vinyl acetate |
| Acetonitrile | Hexachlorobutadiene | Vinyl chloride |
| Acrolein | Hexane | |

Figure A1. Location of samplers during emissions testing on 11 February 2012.

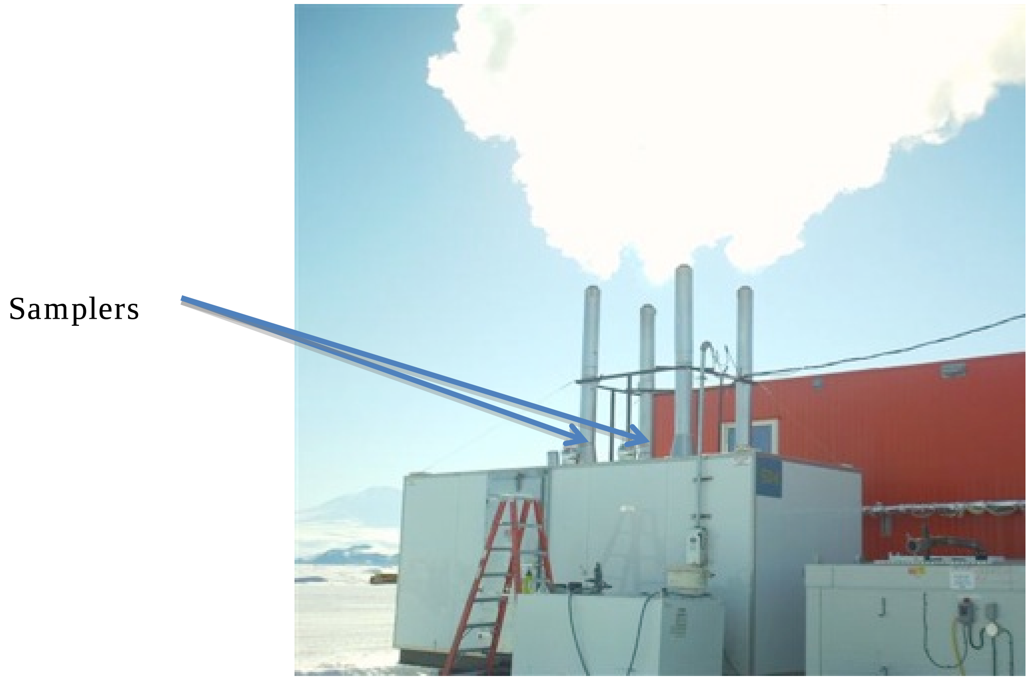


Figure A2. On 14 February 2012, the sampler was placed in the basket of the lift truck and positioned in the exhaust plume as shown.

We attempted to determine the emissions level for VOCs with the catalytic converter installed in the field; however, the backpressure created was too great, and it caused flue gas to leak into the incinerator enclosure, creating a potential health risk. After this occurred, the catalytic converters were removed. Further modification to the incinerator is required for long-term operation with the catalytic converters (i.e., sealing the combustion chamber and flue pipes to prevent exhaust leaks).

Two of these three samples (one from the 11 February sampling and the sole sampling on 14 February) were sent to Hill Labs in New Zealand to determine the VOCs contained in the emissions. Table A3 lists the only compounds found in the emissions that were above the detection limits of the analyzing equipment used by Hill Labs. It is interesting to note that contrary to expectations, the measured concentrations of the detected VOCs are quite comparable even though the sampling locations were different and though one would expect concentrations from the sample taken on 11 February to be much lower.

Table A3. Concentration of VOCs detected in incinerator exhaust emissions. The odor thresholds and odor description is determined from material safety data sheets for each of these compounds.

| Compound | Concentration (μg/m³) | | Odor Threshold (μg/m³) | Odor |
|---|---|---|---|---|
| | 11 Feb. 2012 | 14 Feb. 2012 | | |
| 1,2,4-Trimethylbenzene | 5 | UDL (<5) | 60,000 | Pungent (slight) |
| Acetone | 11 | 10 | 147,000 | Fruity |
| *m,p*-Xylene | 15 | UDL (<10) | 2700 | Differs* |
| Propene | UDL (<2) | 4 | 28,000 | Weak, unpleasant smell |
| Toluene | 6 | UDL (<4) | 600 | Paint thinner |

UDL: under detection limits for that compound

* There are differing smells depending on whether it is *p* (para) or *m* (meta) versions of this compound. The odor associated with *p*-xylene is a urine-like smell while *m*-xylene smells like lacquer thinner.

Of these five detected VOCs, four are likely unburned or partially burned AN-8 fuel. Three of these, trimethylbenzene, xylene, and toluene are all benzene-based compounds with methyl groups attached to the benzene ring. Such compounds are commonly found in Kerosene, JP-8, and AN-8 fuels. The fourth, propene, is likely a partially burned hydrocarbon (i.e., a partially burned benzene ring). The presence of any of these compounds in the incinerator emissions should not be surprising as AN-8 was the fuel used in the incinerator burners.

We also should not be surprised to find acetone in the emissions (Table A3) as this is always present in small quantities in air. As such, we would expect to find this in a sample of air far removed from any emission source.

Also listed in Table A3 is the odor threshold limits for each of these compounds; the levels detected are well below the odor detection thresholds.

## Conclusions and recommendations

Based on the emission levels and identified odor, sulfur dioxide may be the source of the objectionable smell emitted from the incinerator. We recommend that a stack scrubber be explored as a possible means to reduce the concentration of sulfur dioxide emitted from the incinerator.

The level of VOCs measured at PEG is well below odor threshold values and should not be a cause for concern regarding odor. The sampling for these compounds was made some distance from the stack outlet and therefore should be representative of the upper limits of concentrations seen at the ground level where personnel would be present.

There may be other compounds that could be of concern besides what was tested for and reported here (e.g., hydrogen sulfide, $H_2S$, which has a "rotten egg" smell).

# Appendix B: Waste Water Original Sizing Design

Raytheon Polar Services calculated the original design, shown below, as the basis for sizing the two proof-of-concept waste-handling methods. A safety factor (SF) of two, based on the expected waste production, was used in these calculations.

Figure B1. Calculations for estimating waste per person per day at Pegasus Runway.

Method 1

(Small camp rate)

3.8 l/person/day * SF (2) = 7.6 l/person/day

1 liter = 0.2641721 gal

7.6 l / person/day · 0.264 gal / l = 2.007708 Use 2.00 gal/person/day

Site workers = 2-12 hr shifts of 50 workers

100 people/day

2.00 gal / person-day * 100 person-day = 200 gal/day

Operating season = 90 days

Seasonal Volume of wastewater = 200 gal / day * 90 days = 18,000 gal.

(REF) 2008 Master Permit Report

(5.6 · 1.357143 = 7.6) SF = 1.36 large camp rate.

Figure B2. Calculations for total estimated waste per season at Pegasus Runway.

Method 1

LC-130 Flights for season add 1800 gal of waste water.

(REF) 8/27/09 email of Dean Jarosh

Passengers (PAX), Peak Weekly = 2000 person/wk

Peak Day = $\frac{2000 \text{ person}}{\text{wk}} \cdot \frac{1 \text{ wk}}{7 \text{ days}}$ = 285 person/day

(REF) Williams Field data 2008-2009

Use 300 person/day · ~~15%~~ 10% Those that use the facilities

300 · ~~.15~~ 0.10 = ~~45~~ 30 person/day · $\frac{2 \text{ gal}}{\text{person} \cdot \text{day}}$ = 60 gal/~~person~~/day

60 gal/day · 90 days = 5,400 gal of waste water in a season

| TOTAL | | |
|---|---|---|
| | WORKERS | 18,000 GAL |
| | FLIGHTS | 1800 GAL |
| | PAX | 5400 GAL |
| | | 25,200 gallons |

25,000 GAL 7.6 (SF = 2)

9000
1800
2700
13,500 GAL 3.8 (SF = 1)

13,500
1800
4050
19,350 gal 5.6 (SF = 1.35)

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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

**14. ABSTRACT**
Raytheon Polar Services Company implemented two proof-of-concept waste handling methods for testing during the austral summers spanning 2010 to 2013 at Pegasus Airfield, McMurdo, Antarctica. These methods included a portable waste transfer tank and a waste incineration method. Testing and modification of these methods took place from 2010 to 2013 to determine the feasibility of long-term use of each method. Data for the actual waste water production at the runway was limited before the start of these projects and was estimated to determine proper sizing of the two methods used. During proof-of-concept testing of these methods, a more accurate determination of the waste water production was obtained as well. This is invaluable data for developing a long-term solution to handle the wastewater produced at the airfield. Both of these methods proved to be viable options dependent on the amount and type of logistical support available.

**15. SUBJECT TERMS**
Antarctica, EPOLAR, McMurdo Station, NSF, Pegasus Runway, Waste incineration, Waste management, Waste transport

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