# National Aeronautics and Space Administration

# Technology Evaluation for Environmental Risk Mitigation Principal Center

## Hypergolic Propellant Destruction Evaluation

## Cost Benefit Analysis

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# 1.0 Background

At space vehicle launch sites such as Vandenberg Air Force Base (VAFB), Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC), toxic vapors and hazardous liquid wastes result from the handling of commodities (hypergolic fuels and oxidizers), most notably from transfer operations where fuel and oxidizer are transferred from bulk storage tanks or transfer tankers to space launch vehicles.

During commodity transfer at CCAFS and KSC, wet chemical scrubbers (typically containing four scrubbing towers) are used to neutralize fuel saturated vapors from vent systems on tanks and tanker trailers. For fuel vapors, a citric acid solution is used to scrub out most of the hydrazine.

Operation of both the hypergolic fuel and oxidizer vapor scrubbers generates waste scrubber liquor. Currently, scrubber liquor from the fuel vapor scrubber is considered non-hazardous. The scrubber liquor is defined as spent citric acid scrubber solution; the solution contains complexed hydrazine / methylhydrazine and is used to neutralize non-specification hypergolic fuel generated by CCAFS and KSC.

This project is a collaborative effort between Air Force Space Command (AFSPC), Space and Missile Center (SMC), the CCAFS, and National Aeronautics and Space Administration (NASA) to evaluate microwave destruction technology for the treatment of non-specification hypergolic fuel generated at CCAFS and KSC. The project will capitalize on knowledge gained from microwave treatment work being accomplished by AFSPC and SMC at VAFB.

This report focuses on the costs associated with the current non-specification hypergolic fuel neutralization process (Section 2.0) as well as the estimated costs of operating a mobile microwave unit to treat non-specification hypergolic fuel (Section 3.0), and compares the costs for each (Section 4.0).

## 1.1 Scope

The purpose of this document is to assess the costs associated with waste hypergolic fuel. This document will report the costs associated with the current fuel neutralization process and also examine the costs of an alternative technology, microwave destruction of waste hypergolic fuel. The microwave destruction system is being designed as a mobile unit to treat non-specification hypergolic fuel at CCAFS and KSC.

# 2.0 Waste Hypergolic Fuel Neutralization (Baseline Process)

## 2.1 Process Overview

Non-specification hypergolic fuel combined with citric acid solution creates stable (non off-gassing) hydrazine citrate. The chemical reactions and reaction products have been provided below.

- Hydrazine + Citric Acid → Hydrazine Citrate
- $3N_2H_4$ + $C_6H_8O_7$ → 3 $N_2H_5^+$ + (OOC-$CH_2$-C(OH)COO-$CH_2$COO) 3

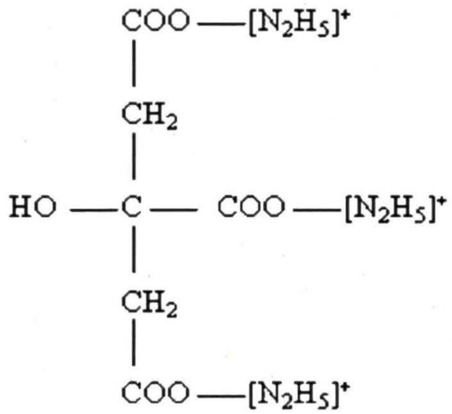


**Figure 1 – Hydrazine Citrate**

- Methylhydrazine + Citric Acid → Methylhydrazine Citrate
- $CH_3N_2H_3$ + $C_6H_8O_7$ → 3 $CH_3N_2H_5^+$ + (OOC-$CH_2$-C(OH)COO-$CH_2$COO)

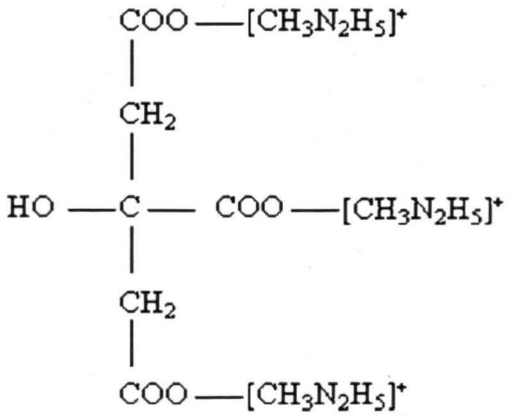


**Figure 2 – Methylhydrazine Citrate**

- Unsymmetrical Dimethyl Hydrazine + Citric Acid → Unsymmetrical Dimethyl Hydrazine Citrate
- $3C_2H_8N_2 + C_6H_8O_7 \rightarrow 3\ C_2N_2H_9^+ + (OOC\text{-}CH_2\text{-}C(OH)COO\text{-}CH_2COO)_3$

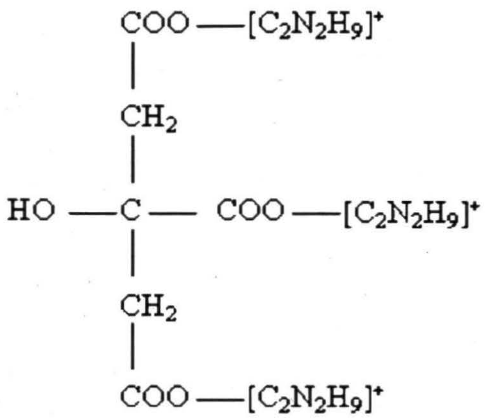


**Figure 3 - Unsymmetrical Dimethyl Hydrazine Citrate**

## 2.2 Process Description

Non-specification hypergolic fuel is neutralized using citric acid solution at the Hypergolic Fuel Transfer Facility located at Fuel Storage Area 1. Several fuel related waste streams, including spent fuel scrubber solution and fuel rinsates, are commingled with non-specification hypergolic fuel during the neutralization.

During the process, partially used fuel scrubber solution (citric acid solution) is mixed with 25% fresh citric acid in a volume calculated to reduce the pH to mid-scale (pH 4-7) and reduce the off-gassing to an acceptable exposure limit {ACGIH TLV[1] 0.01 ppm, time-weighted average (TWA) 8hrs/day; 40hrs/week}. In addition to the citric acid solutions, hydrazine fuel rinsates are combined in a 5,000 gallon waste tanker trailer. A transfer pump is connected to the waste tanker trailer to provide circulation and the fuel waste solution is pressure injected into the circulating stream of the waste tanker trailer. Since this produces an exothermic reaction (gives off heat), the temperature is monitored to maintain a temperature below 135 degrees F so that equipment soft goods are not damaged. The mixing of the citric acid solution and non-hazardous rinsates may be performed in level 'D' personal protective equipment (PPE)[2]. The adding of hazardous rinsates and the waste fuel solution is a self-contained atmospheric protective ensemble (SCAPE) operation. After the neutralization process, the solution is transferred into a

[1] ACGIH TLV--American Conference of Governmental and Industrial Hygienists' threshold limit value expressed as a time-weighted average; the concentration of a substance to which most workers can be exposed without adverse effects.

[2] Occupational Safety and Health Administration (OSHA) - Level D - A work uniform affording minimal protection: used for nuisance contamination only. The following constitute Level D equipment: 1-Coveralls; 2-Gloves (as needed); 3-Boots/shoes, chemical-resistant steel toe and shank; 4-Boots, outer, chemical-resistant (disposable, as needed); 5-Safety glasses or chemical splash goggles (as needed); 6-Hard hat (as needed); 7-Escape mask (as needed); 8-Face shield (as needed)

commercial tanker trailer for off-site transportation and disposal (EVM-I-0446-1; Fuel Storage Area 1 Hazardous Waste Accumulations Sites, Process Instruction).

The neutralized fuel solution falls under Technical Response Package (TRP) HF0028; defined as a hazardous waste. Non-ignitable, non-corrosive water solutions of hydrazine, monomethylhydrazine (MMH), and unsymmetrical dimethylhydrazine from aerozine-50 (UDMH); Hydrazine ≤ 15%, MMH ≤ 15%, UDMH ≤ 1%, IPA < 24%, citric acid < 25%; pH ranges from > 2.0 to approximately 7.0. Optimal pH range to maintain attenuation is 5.0 - 6.0.

The fuel neutralization process is conducted quarterly. Table 1 shows data for quarters 3 and 4 of 2008; quarters 1, 2, 3, 4 of 2009; and quarter 1 of 2010. For non-specification hypergolic fuel, it takes 10 to 20 minutes per cylinder for connection, injection, and disconnection. The column titled "Duration" in Table 1 assumes 20 minutes per cylinder for the connection, injection, and disconnection of non-specification hypergolic fuel cylinders.

**Table 1 – Waste Neutralization Processing**

<table>
<tr><th>Date</th><th>Waste Code</th><th>Amount (gallons)</th><th>Sources</th><th>Duration (minutes)</th></tr>
<tr><td>October 28, 2008</td><td>HB0002</td><td>113</td><td>1. FSA-1 (96 gallons; 4 cylinders)<br>a. 16.1 gallons<br>b. 27.4 gallons<br>c. 25.2 gallons<br>d. 27.3 gallons<br>2. Launch Complex 39B (17 gallons; 1 cylinders)<br>a. 17.2 gallons</td><td>100</td></tr>
<tr><td rowspan="2">January 27, 2009</td><td>HB0002</td><td>30</td><td>1. FSA-1 (28 gallons; 2 cylinders)<br>a. 1.9 gallons<br>b. 26.3 gallons<br>2. Launch Complex 39A (2 gallons; 1 cylinder)<br>a. 2.1 gallons</td><td rowspan="2">80</td></tr>
<tr><td>HB0003</td><td>10</td><td>1. Thrust Vector Control (TVC) Deservicing Building (10 gallons; 1 cylinder)</td></tr>
<tr><td>April 14, 2009</td><td>HB0002</td><td>146</td><td>2. FSA-1 (35 gallons; 2 cylinders)<br>a. 26.4 gallons<br>b. 8.6 gallons<br>3. Launch Complex 39B (105 gallons; 5 cylinders)<br>a. 27 gallons<br>b. 19.9 gallons<br>c. 11.7 gallons<br>d. 19.9 gallons<br>e. 26.4 gallons<br>4. Orbiter Processing Facility (6 gallons; 1 cylinder)<br>a. 6.4 gallons</td><td>160</td></tr>
</table>

| Date | Waste Code | Amount (gallons) | Sources | Duration (minutes) |
|---|---|---|---|---|
| June 25, 2009 | HB0002 | 90.5 | 1. FSA-1 (47.7 gallons; 3 cylinders)<br>a. 6.3 gallons<br>b. 14.2 gallons<br>c. 27.2 gallons<br>2. Launch Complex 39B (42.3 gallons; 3 cylinders)<br>a. 11.2 gallons<br>b. 21.4 gallons<br>c. 9.7 gallons<br>3. Launch Complex 39A (0.5 gallon; 1 cylinder)<br>a. 0.5 gallon | 160 |
| | HB0003 | 9.2 | 1. Thrust Vector Control (TVC) Deservicing Building (9.2 gallons; 1 cylinder) | |
| October 09, 2009 | HB0002 | 55.10 | 1. FSA-1 (53.8 gallons; 3 cylinders)<br>a. 15.3 gallons<br>b. 27.3 gallons<br>c. 11.2 gallons<br>2. Launch Complex 39A (0.3 gallon; 1 cylinder)<br>a. 0.3 gallons<br>3. Launch Complex 39B (1 gallon; 1 cylinder)<br>a. 1 gallon | 120 |
| | HB0003 | 8.7 | 1. Thrust Vector Control (TVC) Deservicing Building (8.7 gallons; 1 cylinder) | |
| January 20, 2010 | HB0002 | 114.5 | 1. FSA-1 (83.9 gallons; 6 cylinders)<br>a. 22.7 gallons<br>b. 6.7 gallons<br>c. 20.7 gallons<br>d. 9.8 gallons<br>e. 3.7 gallons<br>f. 20.3 gallons<br>2. Launch Complex 39A (30.6 gallons; 3 cylinders*)<br>a. 2.8 gallons<br>b. 8.8 gallons<br>c. 19 gallons | 160* |
| | HB0003 | 13.8 | 1. Thrust Vector Control (TVC) Deservicing Building (13.8 gallons; 2 cylinders*)<br>a. 4.2 gallons<br>b. 9.6 gallons | |
| * Wastes generated from Launch Complex 39A and the TVC Deservicing Building were combined into 2 cylinders bringing the total number of cylinders processed on January 20, 2010 to 8 cylinders | | | | |

| Date | Waste Code | Amount (gallons) | Sources | Duration (minutes) |
|---|---|---|---|---|
| April 13, 2010 | HB0002 | 34.7 | 1. FSA-1 (1.5 gallons; 2 cylinder*)<br>a. 1.5 gallons<br>b. 4.3 gallons<br>2. Launch Complex 39A (33.2 gallons; 5 cylinders*)<br>a. 0.3 gallons<br>b. 0.4 gallons<br>c. 28.3 gallons<br>d. 4.2 gallons | 40* |
| | HB0003 | 9.4 | 1. Thrust Vector Control (TVC) Deservicing Building (9.4 gallons; 1 cylinder*) | |
| * Wastes generated from FSA-1, Launch Complex 39A and the TVC Deservicing Building were combined into 2 cylinders for processing on April 13, 2010 | | | | |

### 2.3 Cost Estimates

Cost estimates have been developed for the current fuel neutralization process taking into account the following factors:

- Capital and Installation
- Operating Materials
- Labor
- Energy
- Maintenance
- Waste Disposal

The cost factors were obtained during communications with the NASA contractors that perform the neutralization of non-specification hypergolic fuel for KSC and CCAFS.

#### 2.3.1 Capital and Installation Costs, Petro-Steele tanker trailer

Costs associated with the initial purchase of the 5,000 gallon waste tanker trailers are not being considered since the tanker trailers have been in service for more than a decade.

#### 2.3.2 Operating Materials Costs, Non-Specification Hypergolic Fuel Neutralization Process

Citric acid is the primary commodity required during the neutralization process, which is conducted to remove the poisonous by inhalation and corrosive hazards from the hypergolic fuel solution prior to transport.

At the time of this report, citric acid is being procured in 50 pound waterproof bags at a cost of $55 per bag ($1.10 per pound), procured to Federal Standard A-A-59147. In review of the last five non-specification hypergolic fuel neutralization processes, an average of 1,500 pounds of citric acid was used per neutralization.

**Table 2 – Operating Materials Costs, Non-Specification Hypergolic Fuel Neutralization Process**

| Product | Quantity Used (lbs) – Annually | Cost/Lb. | Annual Cost |
|---|---|---|---|
| Citric Acid | 6,000 (5 previous neutralization processes averaged 1,500 lbs/qtr) | $1.10 | $6,600 |

### 2.3.3 Labor Costs, Non-Specification Hypergolic Fuel Neutralization Process

Labor hours and occupational specialties were obtained from the NASA contractor responsible for conducting the quarterly hypergolic fuel neutralization for KSC and CCAFS. Labor rates were estimated utilizing the U.S. Bureau of Labor Statistics (www.bls.gov/bls/blswage.htm) listed rates for median hourly earnings for the occupation which most closely matched the occupational specialty provided by the contractor. General and administrative (G&A) expenses were factored into the estimated labor rates.

Labor hours required for the preventive maintenance procedures were obtained from the NASA contractors responsible for conducting the quarterly hypergolic fuel neutralization process for KSC and CCAFS. Labor rates were estimated using the average hourly billable rate charged by several tanker truck/trailer maintenance and repair facilities that are authorized to conduct the required U.S. Department of Transportation (DOT) tests and inspections.

**Table 3 – Labor Costs, Non-Specification Hypergolic Fuel Neutralization Process**

| Occupation | Hours/Year | Estimated Labor Rate $ / hr | Annual Cost |
|---|---|---|---|
| Propellant Engineer | 128 | $62.56 | $8,007.68 |
| Propellant Technician | 256 | $51.03 | $13,063.68 |
| Industrial Hygienist | 64 | $51.17 | $3,274.88 |
| Health & Safety Engineer | 128 | $49.77 | $6,370.56 |
| Life Support Technician | 128 | $46.60 | $5,964.80 |
| DOT Certified Mechanic | 123 (five year average) | $77.00 | $9,471.00 |
| Total | 827 | | $46,152.60 |

### 2.3.4 Energy Costs, Non-Specification Hypergolic Fuel Neutralization Process

No energy costs were captured for the non-specification hypergolic fuel neutralization process.

### 2.3.5 Maintenance Costs, Petro-Steele tanker trailer

Preventive maintenance on the Petro-Steele tanker trailer is conducted on a quarterly, annual, biennial, and five-year basis per OMI Q6785, "Tanker, Petro-Steel, 5,000 gallon, LT-65 through LT-76, KSC and CCAFS". Preventive maintenance procedures can require the replacement of filters, fluids, belts, hoses and other components as required. For this effort, it has been estimated that the annual cost of replacement parts will be $2,000.

**Table 4 – Maintenance Costs, Petro-Steel Tanker Trailer**

| Petro-Steel Tanker Trailer | Annual Cost |
|---|---|
| Replacement Parts | $2,000 |

### 2.3.6 Waste Disposal Costs, Neutralized Fuel Solution

The neutralized fuel solution falls under TRP HF0028; defined as a hazardous waste. Following the fuel neutralization process, the neutralized fuel solution is transferred to a vendor tanker trailer and shipped to EQ Florida, Inc., Tampa, Florida. Disposal of the neutralized fuel solution has been estimated to cost $30,000, including G&A expenses, per shipment.

**Table 5 – Waste Disposal Costs, Neutralized Fuel Solution**

| Waste Disposal | Cost per Shipment | Shipments per Year | Annual Cost |
|---|---|---|---|
| Neutralized fuel solution; HF0028 | $30,000 | 4 | $120,000 |

# 3.0 Microwave Destruction of Waste Hypergolic Fuel

## 3.1 Process Overview

Nitrogen is used to stream non-specification hypergolic fuel to the microwave system. Quartz reactor tubes (20 in total) in the microwave system are filled with pelletized activated carbon (PAC). The PAC is extremely porous; having a very large surface area which adsorbs all hypergolic vapors contained in the nitrogen stream.

In the presence of activated carbon, microwave energy induces the decomposition of $N_2H_4$, MMH ($CH_3N_2H_3$), and UDMH ($(CH_3)_2N_2H_2$) into hydrogen ($H_2$), methane ($CH_4$) and nitrogen ($N_2$) as shown in the following equations:

- $N_2H_4 \rightarrow N_2 + 2H_2$
- $CH_3N_2H_3 \rightarrow N_2 + H_2 + CH_4$
- $(CH_3)_2N_2H_2 \rightarrow N_2 + 2CH_4$

In addition, a small amount of hydrazine is decomposed to form ammonia;

- $2N_2H_4 \rightarrow N_2 + H_2 + 2NH_3$

Laboratory experimental data indicates that the concentration of ammonia in the product stream from the microwave reactor is negligible because the ammonia is also decomposed by microwave energy into $N_2$ and $H_2$ in the presence of the activated carbon.

## 3.2 Process Description

The microwave system is expected to be operated at Fuel Storage Area 1, Hypergolic Fuel Transfer Facility 77800. Thirty-gallon cylinders specifically designated for non-specification hypergolic fuel will be connected to the microwave system using tubing and fittings constructed per KSC-GP-425G, Fluid Fittings, Engineering Standards.

Once all fittings are secured, the microwave system will be fully automated and controlled by a Programmable Logic Controller (PLC). Following a preset reactor warm-up period, the reactors are purged with nitrogen. The nitrogen enters into the first stage microwave reactors through an orifice plate which serves to limit the maximum gas flow through the system. The nitrogen flow is equally divided and enters into the first stage microwave reactors. A part of the nitrogen purges flows through a pressure regulator and orifice into the 30-gallon non-specification hypergolic fuel cylinders to feed the non-specification hypergolic fuel to the first stage microwave reactors.

After the warm-up period, valves are actuated to begin the flow of non-specification hypergolic fuel into the first stage microwave reactors. The liquid fuel enters the first stage microwave reactors through an orifice plate which serves to limit the maximum flow; a pressure regulator controls the flow rate. The liquid non-specification hypergolic fuel flow is equally divided and enters into the first stage microwave reactors.

The 30-GPH microwave scrubber consists of 5 units of skid-mounted microwave system. The unit has two 6-kW first stage microwave reactors and two 3-kW second stage microwave reactors. Figure 4 shows the process flow diagram for a single microwave scrubber unit.

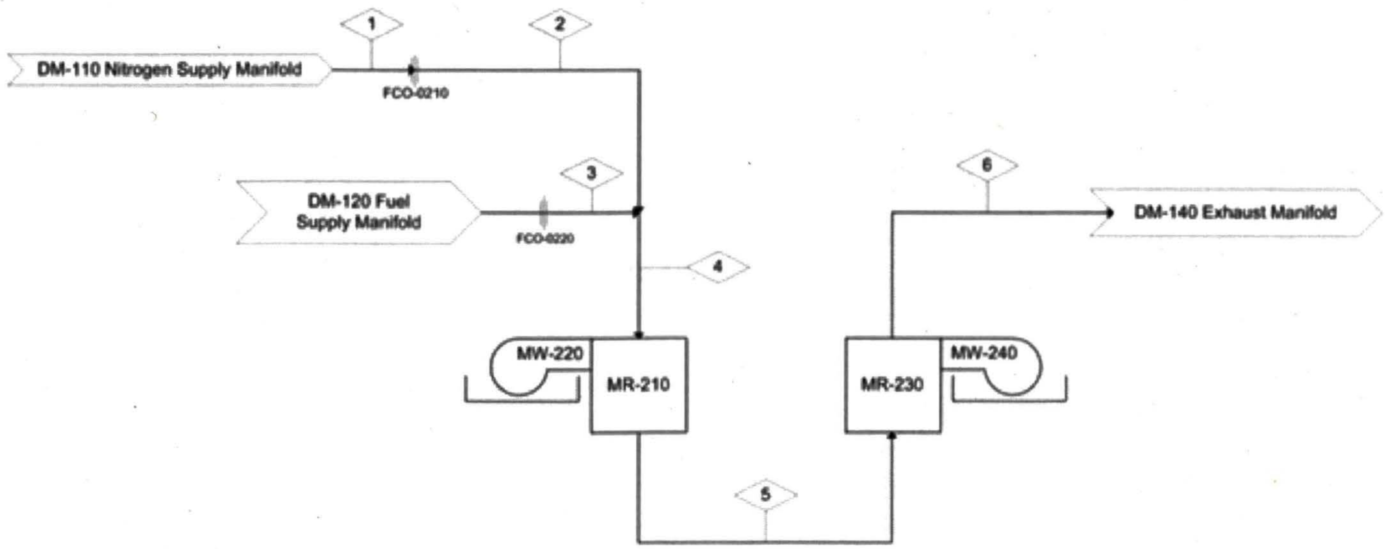


**Figure 4 - Single Microwave Scrubber Unit**

### 3.3 Cost Estimates

Cost estimates have been developed for the microwave system taking into account the following factors:

- Capital and Installation
- Operating Materials
- Labor
- Energy
- Maintenance
- Waste Disposal

The cost factors were obtained during communications with the inventor / designer of the microwave system, Dr. Chang Yul Cha, Cha Corporation.

#### 3.3.1 Capital and Installation Costs, Microwave System

The 30-GPH portable microwave system is estimated to cost $2,147,745 to fabricate and install at Fuel Storage Area 1. Modifications to the microwave system and potentially to the facilities where the microwave system will operate could be mandated, these costs are captured as incidentals. Once installed, the microwave system is expected to operate for 20 years.

**Table 6 - Capital and Installation Costs, Microwave System**

| Items | Estimated Cost, $ |
|---|---|
| Equipment and Construction Materials | 1,313,565 |
| Construction Labor including construction drawings | 689,000 |
| Testing and Modification of the Unit | 74,980 |
| Microwave Scrubber Shipping | 10,400 |
| Labor Costs for Acceptance Testing and Field Operator Training | 47,200 |
| Travel Expenses for Microwave Scrubber Field Testing | 12,600 |
| **Total** | **2,147,745** |

In addition to capital and installation costs, there will be costs associated with obtaining RCRA Part A and Part B Subpart X permits. For this document, costs associated with permitting are estimated to be $500,000. This cost is attributed to the labor and fees required to obtain the RCRA permits. All aspects of the microwave unit will need to be reviewed, tested and analyzed. A complete analysis of the reactions, products, and by-products will be required for the RCRA Part A and Part B Subpart X permit submittal.

Additional costs associated with permitting as well as maintenance are discussed in section 4.2 "Uncertainly Analysis".

### 3.3.2 Operating Materials Costs, Microwave System

Once built and installed, the only operating material associated with the microwave system is activated carbon. The activated carbon is rarely changed out or replaced so there is no cost associated with operating materials for the microwave system.

### 3.3.3 Labor Costs, Microwave System

Operation of the microwave system is expected to require less labor support than the current non-specification hypergolic fuel neutralization process. Since the microwave system operates by Programmable Logic Controller (PLC), manual labor is not required once the proper connections are made from the 30-gallon non-specification hypergolic fuel cylinders to the microwave system.

It is expected that the same personnel associated with the non-specification hypergolic fuel neutralization process will continue to monitor the operation of the microwave system, however, due to the automated system the total work hours are expected to decrease. The microwave system operates only 4 hours per quarter. For operation of the microwave system, it has been estimated that there will be a 50% reduction in labor hours for all associated occupations when compared to the current non-specification hypergolic fuel neutralization process.

**Table 7 – Labor Costs, Microwave System**

| Occupation | Hours/Year | Estimated Labor Rate $ / hr | Annual Cost |
|---|---|---|---|
| Propellant Engineer | 64 | $62.56 | $4,003.84 |
| Propellant Technician | 128 | $51.03 | $6,531.84 |
| Industrial Hygienist | 32 | $51.17 | $1,637.44 |
| Health & Safety Engineer | 64 | $49.77 | $3,185.28 |
| Life Support Technician | 64 | $46.60 | $2,982.4 |
| Total | 352 | | $18,340.80 |

### 3.3.4 Energy Costs, Microwave System

The microwave system requires electrical line connections for 440-volt, 3-phase, 600 Amp. The following factors were used to calculate electricity use for the microwave system:

- Watts = Amps x Volts
- Kilowatt = 1000 watts

**Table 8 - Energy Consumption, Microwave System**

| Amps | Volts | Watts | Kilowatts |
|---|---|---|---|
| 600 | 440 | 200,000 | 200 |

The microwave system is expected to eliminate 30 gallons (250 lbs/hr) of non-specification hypergolic fuel per hour. Based on the last three non-specification hypergolic fuel neutralization processes, an average of 96 gallons of non-specification hypergolic fuel are treated quarterly. The microwave system is expected to operate for 4 hours per quarter, four quarters per year; 16 hours treating non-specification hypergolic fuel and 4 hours for reactor warm-up and system shut down. The following factors were used to estimate the annual cost for electricity used to operate the microwave system:

- Kilowatt Hour (kWh) = Kilowatt x Hours used
- $0.12 per kilowatt hour = "Average Retail Price of Electricity to Ultimate Customers, All Sectors, Florida"; Energy Information Administration - http://www.eia.doe.gov

**Table 9 – Energy Costs, Microwave System**

| Operating Time | Energy Use | | Cost | |
|---|---|---|---|---|
| (hours / year) | kilowatt | kilowatt hour | $ / kWh | $ / year |
| 20 | 200 | 4,000 | $0.12 | $480 |

### 3.3.5 Maintenance Costs, Microwave System

The microwave system is designed to require minimal maintenance. While little maintenance is required, regularly scheduled cleaning and inspection of the unit will help to assure optimum performance and longevity of the microwave system. Some miscellaneous components may require replacement during the cleaning and inspection activities.

**Table 10 – Maintenance Costs, Microwave System**

| Occupation | Hours/Year | Estimated Labor Rate $ / hr | Annual Cost |
|---|---|---|---|
| Propellant Engineer | 40 | $62.56 | $2,502.40 |
| Propellant Technician | 80 | $51.03 | $4,082.40 |
| Health & Safety Engineer | 40 | $49.77 | $1,990.80 |
| Components | | | $7,000.00 |
| Total | 160 | | $15,575.60 |

### 3.3.6 Waste Disposal Costs, Microwave System

No hazardous wastes and only small amounts of nonhazardous waste are expected to be produced from the operation of the microwave system. The activated carbon (pelletized activated carbon that does not break down easily) in the microwave reactor acts as a catalyst and does not react with any of the fuel components and is not consumed during operation. If an activated carbon change-out was required, the microwave system would be run under full power with just nitrogen being fed into the microwave reactor; this would remove any trace contaminants from the carbon prior to opening up the system and replacing the activated carbon. After that procedure, any fuel components would be driven from the activated carbon, making it non-hazardous waste.

# 4.0 Cost Comparison

## 4.1 Life Cycle Cost Analysis

A side by side comparison of the cost factors for the fuel neutralization process and the microwave system are presented in Table 11 and
Table 12. The cost estimates were obtained during communications with the NASA contractors that perform the fuel neutralization process for KSC and CCAFS and from the inventor / designer of the microwave system.

**Table 11 – Annual Operating Cost Comparison, Fuel Neutralization to the Microwave System**

| Cost Factors | Fuel Neutralization | Microwave System |
|---|---|---|
| Operating Materials | $6,600 | $0 |
| Labor | $46,153 | $18,340 |
| Energy | $0 | $480 |
| Maintenance | $2,000 | $15,575 |
| Waste Disposal | $120,000 | $0 |
| **Total** | $174,753 | $34,395 |

**Table 12 - Capital Cost Comparison, Fuel Neutralization to the Microwave System**

| Cost Factors | Fuel Neutralization | Microwave System |
|---|---|---|
| Capital and Installation | $0 | $2,147,745 |

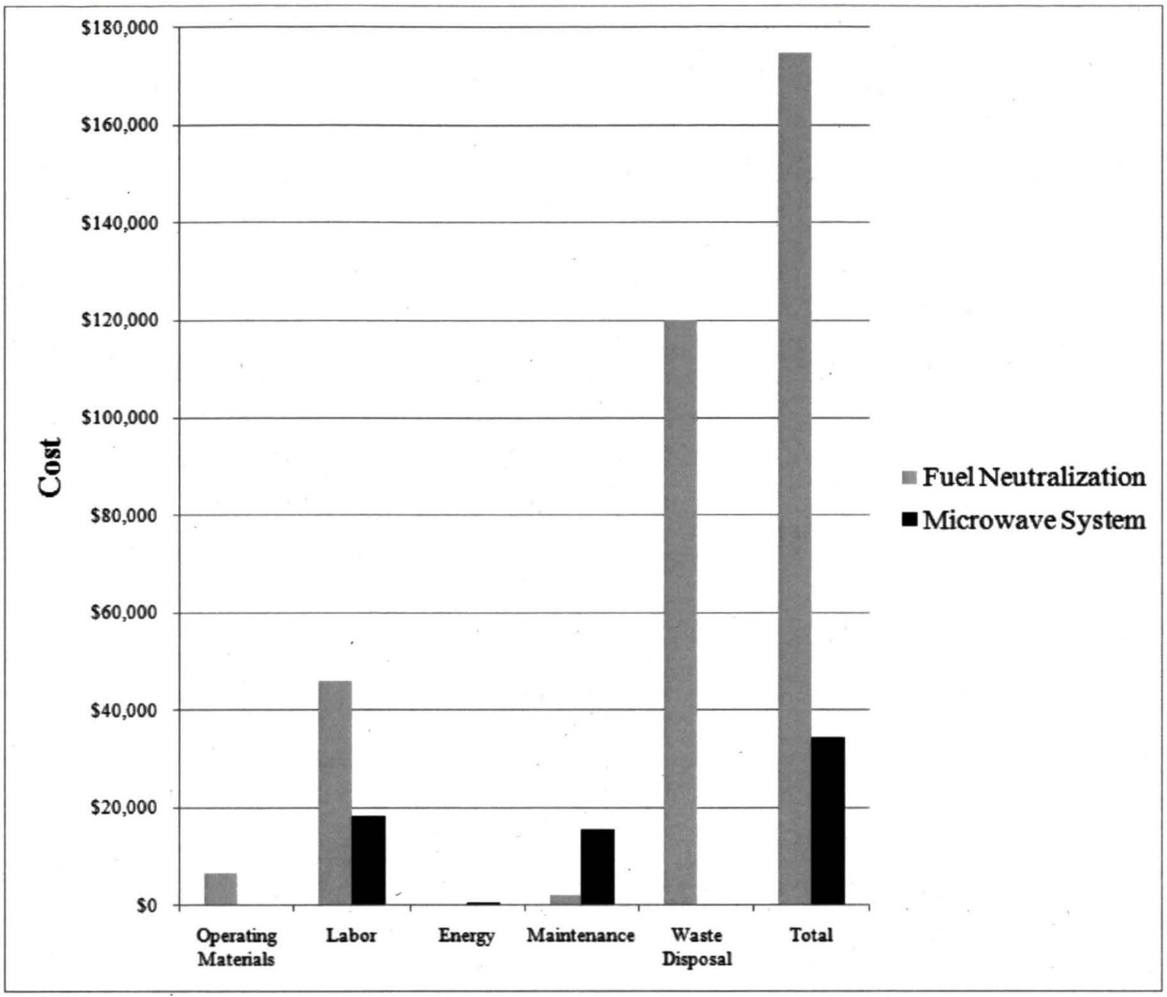


**Figure 5 - Cost Comparison, Annual Operating Costs**

The microwave system is expected to have a life-cycle of 20 years. Based upon the annual operating costs, Table 11 and Figure 5, the microwave system is estimated to cost less to operate per year than the current fuel neutralization process. In order to calculate capital payback for the microwave system, initial capital cost for the microwave system was divided by the estimated annual costs savings for operating the microwave system versus the fuel neutralization process. Table 13 shows an expected capital payback of 15 years for the microwave system. Over the expected life-cycle of the microwave system, 20 years, it is estimated that a total of $2,807,160 will be saved versus operation of the current fuel neutralization process.

**Table 13 - Capital Payback, Microwave System**

| Initial Capital | Annual Savings | Payback Period (Years) | Life-Cycle Savings (20 years) |
|---|---|---|---|
| $2,147,745 | $140,358 | 15 | $2,807,160 |

## 4.2 Uncertainty Analysis

There are some concerns regarding the microwave system that are not captured in the analysis above but will increase the overall cost of the microwave unit.

### 4.2.1 Permitting, Microwave System

The Resource Conservation and Recovery Act (RCRA) are administered by the United States Environmental Protection Agency (USEPA) and establish requirements for cradle-to-grave (generation, storage, transportation, treatment/disposal, etc.) management of hazardous waste. The EPA has authorized the Florida Department of Environmental Protection (FDEP) to oversee and enforce RCRA requirements in the State of Florida. KSC is a "Large Quantity Generator" of hazardous waste and is subject to stricter requirements for hazardous waste storage. KSC also operates a permitted hazardous waste storage facility which is operated by the KSC Medical and Environmental Support Contractor.

EPA is required by Section 3004 of the Resource Conservation and Recovery Act (RCRA) to establish standards for owners and operators of facilities that treat, store, or dispose of hazardous waste to protect human health and the environment. These standards establish the duties of and provide the basis for issuing permits to the owners and operators of hazardous waste treatment, storage, and disposal facilities (TSDFs) under Section 3005 of RCRA.

Under RCRA, the treatment of a U-listed waste (hydrazine) and a P-listed waste (MMH) using a mobile microwave unit would require a permit as a miscellaneous unit under 40 CFR 264 Subpart X. P- and U-listed wastes are those designated on the respective lists under RCRA and are hazardous wastes when disposed of unused. Units covered under Subpart X do not fit neatly within the definition of the more typical waste management units described in Part 264 (containers, tanks, incinerators, etc.). To be permitted, Subpart X units must meet environmental performance standards, while other Part 264 units must meet specific technology standards.

RCRA TSDF permits are issued on a site-specific basis. Transportable units have been under discussion for some time and EPA acknowledges that the current RCRA regulations do not include sufficient flexibility to routinely permit transportable units and minimize risk from shipping hazardous waste to TSDF facilities that have site-specific RCRA permits. Thus, to destroy waste hypergolic fuel at KSC/CCAFS, a RCRA Part A and Part B Subpart X permit would need to be obtained unless the material is determined to not be a waste.

Obtaining a RCRA Part A and Part B Subpart X permit is not expected to be an easy process. All aspects of the microwave unit will be reviewed. A complete analysis of the reactions, products, and by-products will be required for the RCRA Part A and Part B Subpart X permit submittal. It has been estimated that the RCRA Part A and Part B Subpart X permit submittal could cost $500,000.

### 4.2.2 Additional Maintenance Costs, Microwave System

If the microwave system requires the replacement of a microwave magnetron tube, the annual operating cost for a given year would be higher. Microwave magnetron tubes are expected to last for 3,500 operating hours. Based on the annual hours of operation required for the microwave system to treat non-specification hypergolic fuel (Table 9), the microwave system is expected to reach the end of its life-cycle before requiring the replacement of a magnetron tube. If a magnetron tube fails unexpectedly, magnetron tubes cost $1,500 for 3-kW and $4,000 for 6-kW to replace.

**Table 14 – Adjusted Maintenance Costs, Microwave System**

| Occupation | Hours/Year | Estimated Labor Rate $ / hr | Annual Cost |
|---|---|---|---|
| Propellant Engineer | 40 | $62.56 | $2,502.40 |
| Propellant Technician | 80 | $51.03 | $4,082.40 |
| Health & Safety Engineer | 40 | $49.77 | $1,990.80 |
| Components | | | $7,000.00 |
| Total | 160 | | $15,575.60 |
| Magnetron Tube | | | $7,500 |
| **Adjusted Maintenance Cost** | | | **$23,075.60** |

The 30-GPH microwave system consists of five skid-mounted microwave units which can be moved by fork lift. Limiting the mobility of the microwave unit reduces damage caused by vibration and jarring associated with road travel. The microwave system operates for only 20 hours per year and is expected to have a life cycle of at least 20 years.

### 4.2.3 Adjusted Capital Payback

As stated previously, the microwave system is expected to have a life-cycle of 20 years. The microwave system is estimated to cost less to operate per year than the current fuel neutralization process. However, capital costs and RCRA permitting costs will be incurred. An adjusted capital payback for the microwave system was calculated by taking the initial capital cost plus RCRA permitting cost and dividing by the estimated annual costs savings for operating the microwave system versus the fuel neutralization process. Table 15 shows an adjusted capital payback of 19 years for the microwave system. Over the expected life-cycle of the microwave system, 20 years, it is estimated that a total of $2,807,160 will be saved versus operation of the current fuel neutralization process.

**Table 15 – Adjusted Capital Payback, Microwave System**

| Initial Capital | RCRA Part A and Part B Subpart X permit | Annual Savings | Payback Period (Years) | Life-Cycle Savings (20 years) |
|---|---|---|---|---|
| $2,147,745 | $500,000 | $140,358 | 19 | $2,807,160 |

## 5.0 Additional Permitting & Compliance

In addition to RCRA, there are several other Federal and State of Florida laws and regulations that govern the management and disposal of certain non-hazardous waste streams. These other regulated waste streams are labeled "controlled waste" at KSC.

At KSC, the NASA Environmental Assurance Branch (EAB) is responsible for implementation of a hazardous, controlled, and solid waste management program. Each waste generator at KSC is responsible for developing general and site-specific waste management procedures for their operations to promote consistency, minimize risk, and ensure compliance with Federal and State of Florida regulatory requirements. To ensure compliance, the EAB established a center-wide process to evaluate, identify, and dispose of hazardous and controlled waste streams generated at KSC. Hazardous and controlled waste evaluation, pickup, and disposal services are provided by the KSC Waste Management Office which is operated by the KSC Medical and Environmental Support Contractor.

The KSC requirements for hazardous and controlled waste management are found in the Kennedy NASA Procedural Requirements document KNPR 8500.1, Chapter 13. Specific procedures for obtaining hazardous and controlled waste support from the KSC Medical and Environmental Support Contractor are found in EVS-P-0001 – Spaceport Waste Services Guidance Manual. KSC is currently considered a synthetic minor source of Hazardous Air Pollutants (HAPs). Minor sources emit less than 25 tons per year of all HAP compounds and less than 10 tons per year of any single HAP compound. In order to comply with USEPA Clean Air Act regulations, KSC maintains a Title V Air Operation Permit which is issued by the Florida Department of Environmental Protection (FDEP). Hypergol fueling and servicing activities are listed as one of the four categories of permitted air emission units on the Title V Permit.

Prior to operation of the microwave scrubber system a formal update to the Title V Air Permit will be required. This can be accomplished by KSC EAB submitting FDEP Form 62-701.900(32) (Application for a Permit to Construct and Operate a Research, Development and Demonstration Facility) and obtaining FDEP's approval. This will also allow air monitoring to occur and the HAPs from the vapor stream to be quantified and reported during the testing phase of the scrubber system.

## 6.0 Conclusions

Based on the estimated annual operation costs generated for this report, the microwave system appears to make financial sense when compared to the current non-specification hypergolic fuel neutralization process. If the microwave system is allowed to operate in-place, in its current design configuration, at Fuel Storage Area 1, a significant annual cost savings will be obtained over the current non-specification hypergolic fuel neutralization process (Table 11 and Figure 5). These annual operating cost savings would offset the capital investment required for the microwave system in relatively short duration.