AD-A130 445 EVALUATION OF NAVAL STATION MAYPORT HEAT RECOVERY INCINERATOR - OCTOBER 1981 - JUNE 1982(U) VSE CORP OXNARD CA JUN 83 NCEL-CR-83.034 N00123-83-C-0149 1/1

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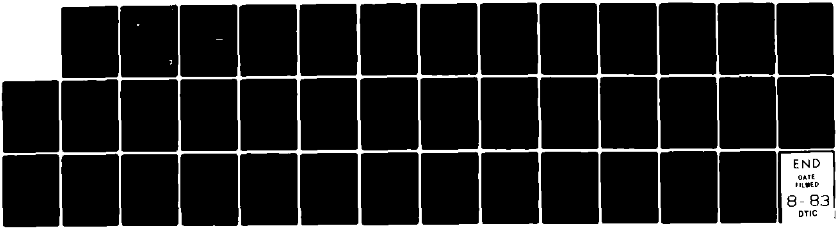

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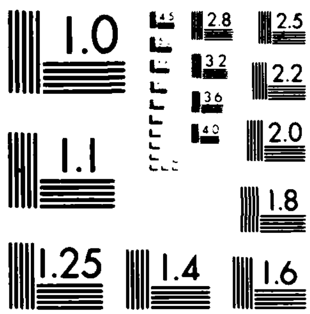

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CR 83.034

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

EVALUATION OF NAVAL STATION MAYPORT HEAT RECOVERY INCINERATOR - OCTOBER 1981 - JUNE 1982

June 1983

An Investigation Conducted by
VSE CORPORATION
3410 South A Street
Oxnard, California

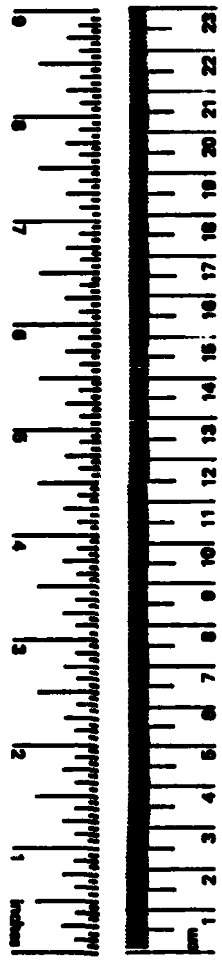
N00123-83-C-0149

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

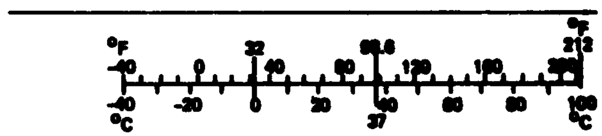
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is the second report which addresses the long-term evaluation of the Mayport Heat Recovery Incinerator program. Operational data was collected from 29 Sep 1981 to 27 Jun 1982 and then analyzed for reliability, availability, maintainability, thermal efficiency, and operating cost.

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FOREWORD

This report is the second in a series of reports on the operation of the Heat Recovery Incinerator (HRI) at Naval Station Mayport covering the period of October 1981 to June 1982. The first report, CR 82.029, "Reliability, Maintainability, Availability; Thermal Efficiency, and Cost Effectiveness Evaluation of Naval Station Mayport HRI," by VSE Corporation covered data received from October 1980 to September 1981. The performance of the HRI improved from FY81 to FY82. The cost of steam production decreased 37%, thermal efficiency increased 15%, processing rate increased 35%, and the reliability and availability increased 65% and 60%, respectively. NCEL is preparing a comparison of the FY81 and FY82 results to be published in September 1983.

Other aspects of the overall solid waste to energy project being conducted by NCEL under the sponsorship of the Naval Facilities Engineering Command includes a study of Refuse Derived Fuel (RDF) use in Navy fossil fuel boilers; survey method for estimating solid waste generation at shore facilities, and a methodology for predicting the economic feasibility of HRI technology at Naval Shore Facilities.

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I. INTRODUCTION

The Resource, Conservation and Recovery Act (RCRA PL94-580) of 1976 mandates the use of fuel derived from recovered material to the maximum extent practicable in Federally owned fossil fuel-fired energy systems. The Naval Station (NS) Mayport, Heat Recovery Incinerator (HRI) installation is one of two Naval facilities in Florida designed to recover energy from solid waste generated on base. The other is located at Naval Air Station (NAS), Jacksonville. By the incineration of waste materials, the NS Mayport HRI is intended to reduce landfill problems, and generate steam to be used by Naval ships at port as well as shore activities.

A. Purpose. The purpose of this task is to evaluate the performance of the HRI in terms of Reliability, Availability, and Maintainability (RAM) parameters, long-term cost-effectiveness, and overall thermal-efficiency. Results will be used to develop Navy criteria for the optimum plant design in the 50 ton per day (TPD) range.

B. Scope. This task involved condensing operational data logged for a nine-month period (October 81 to June 82) into 9 sets of monthly data. This data was then analyzed and used to compute RAM parameters, thermal-efficiency and operating costs of the HRI using the guidance of Naval Civil Engineering Laboratory (NCEL) Memorandum M-63-80-11.

To condense the data and perform the analysis and subsequent calculations, a thorough understanding of the functional operation of the HRI was required. These efforts were supported by the following reference documents:

(1) "Memorandum of procedure for FY-81 evaluation of the NS Mayport HRI for Reliability and Maintainability", by Dr. Suresh C. Garg, Sept. 1980 - M63-80-11.

(2) "Test and Evaluation of the Heat Recovery Incinerator System at Naval Station, Mayport, Florida", an investigation conducted by Systech Corporation, May 1981 - CR81.012.

(3) "Operation and Maintenance Manual: Refuse Incinerator Mayport Naval Station."

(4) Reliability, Maintainability, Availability; Thermal Efficiency; and Cost-Effectiveness Evaluation of Naval Station Mayport Heat Recovery Incinerator (FY 81 data) - CR82.029.

A site visitation along with numerous conversations with HRI contractor personnel and NCEL HRI project personnel provided additional insight.

II. SUMMARY

The following parameters are the result of the long-term evaluation of the heat recovery incinerator at Navy Station Mayport, Florida, for the first three quarters of fiscal year 1982.

A. Reliability, Availability, Maintainability

Function	R*	A_o	MTBF** (hrs)	MTBMA (hrs)	# of Failures	# of Maint. Actions
Incinerate and produce steam with solid waste	0.648	0.792	277	171	13	8
Incinerate solid waste only	0.717	0.810	360	225	10	6
Produce steam without solid waste	0.846	0.819	719	514	5	2

*Based on 120 hour mission
**Based on an operating time of 3596 hours

B. Overall HRI System Parameters

Thermal-Efficiency (TE) = 0.48

Specific Total Manhours (STM) = 0.345 manhours/10^6 Btu

Average Cost of Steam (ACS) = \$5.74/10^6 Btu

Percentage Landfill Reduction (PLR) = 64%

Fuel Oil per Ton of Waste = 16 gallons/ton

Solid Waste Processing Rate (PR) = 1.49 tons/hour

C. Breakdown of Time Categories

T_a = 3596 hours (Time spent operating the HRI)

T_b = 317 hours (Time spent in active preventive maintenance)

T_c = 130 hours (Time spent in active corrective maintenance)

T_d = 1904 hours (Time the HRI was idle and operational)

T_e = 499 hours (Time the HRI was idle and not operational)

III. TECHNICAL DISCUSSION

A. FY-82 HRI Performance Profile

This section provides a summary of the data collected and the resulting RAM, efficiency, and cost parameters for the NS Mayport HRI installation during the first nine months of FY-82.

Table 1 provides the totals of the various times, fuel, water and waste consumed and the steam produced during the test period. All the parameters represent the information for 273 calendar days (i.e. 6552 hours) and 195 operating days (i.e. 4680 hours). Of the total possible hours (6552), the HRI installation spent 3596 hours operating, 447 hours in maintenance (both preventative and corrective), and 2403 hours of idle time (operational and non-operational combined). This idle time is made up mostly of weekends and holidays when the HRI did not run. Under normal operating conditions, the HRI was idle from midnight Friday night until midnight Sunday night with approximately 6 hours (calendar time) of that time spent in scheduled maintenance. A monthly breakdown of all time and energy consumption categories is contained in Appendix A.

Table 1. NS Mayport HRI Summary Data.

	Three-Quarter FY-82 Data Base	Value
	TIME CATEGORY	
1.	Calendar Time in Operation (incinerator, boiler)	3,596 hours
2.	Calendar Time in Operation (overhead crane, ash conveyor and feed ram)	3,249 hours
3.	Man-hours spent in Operation	11,184 hours
4.	Calendar time in Corrective Maintenance	130 hours
5.	Man-hours spent in Corrective Maintenance	216 hours
6.	Calendar time in Routine Maintenance	317 hours
7.	Man-hours spent in Routine Maintenance	871 hours
8.	Time HRI idle, but operational	1,904 hours
9.	Time HRI idle, not operational	499 hours
	FUEL, WATER, WASTE, STEAM	
10.	Fuel waste oil consumed	110,458 gallons
11.	Fuel oil consumed	353 gallons
12.	Makeup water consumed	4,227,250 gallons
13.	Blowdown	688,814 gallons
14.	Solid waste incinerated	4,846 tons
15.	Solid waste rejected (hand-picked)	313 tons
16.	Wet ash	1,546 tons
17.	Fly ash	19 tons
18.	Steam produced	29,933,846 pounds

Table 2 provides the description of the maintenance actions that were performed on the HRI. A maintenance action includes any task that requires the replacement of a failed component, adjustment or unjamming of an item, and any other action necessary to restore the HRI to full operation. There were 21 maintenance actions that included 13 failures. The most frequent problem areas included the overhead crane (five failures) and the incinerator stoker grates (five maintenance actions including one failure). Appendix B provides a detailed listing by functional area for each of the maintenance actions.

Table 2. NS Mayport HRI Maintenance Action Summary Data.

	Equipment	Failures	Other
1.	Front-end loader, overhead crane, hopper, feed ram.	6	2
2.	Incinerator	3	4
3.	Ash conveyor	1	0
4.	Boiler, deaerator, ID fan	3	2
	TOTALS	13	8
	Function		
5.	Incinerate and produce steam with solid waste (requires 1-4 above)	13	8
6.	Incinerate solid waste (requires 1-3 above)	10	6
7.	Produce steam without solid waste (requires 2 and 4 above)	5 *	2 **

* Stoker failure removed from 2 above for this function.
** Four stoker maintenance actions removed from 2 above for this function.

Table 3 provides the RAM, thermal-efficiency and cost parameters for the period of time covered by this report.

Table 3. NS Mayport HRI RAM, Thermal-Efficiency, Cost.

Parameter	Value
1. Mean-Time-Between-Failures (MTBF)	
a. Incinerate and produce steam with solid waste ($MTBF_1$)	277 hours
b. Incinerate solid waste ($MTBF_2$)	360 hours
c. Produce steam without solid waste ($MTBF_3$)	719 hours
2. Mean-Time-Between-Maintenance Actions (MTBMA) (includes failures and other maintenance actions (i.e. adjustments)	
a. Incinerate and produce steam with solid waste ($MTBMA_1$)	171 hours
b. Incinerate solid waste ($MTBMA_2$)	225 hours
c. Produce steam without solid waste ($MTBMA_3$)	514 hours
3. Reliability (R)	
a. Incinerate and produce steam with solid waste (R_1)	0.648
b. Incinerate solid waste (R_2)	0.717
c. Produce steam without solid waste (R_3)	0.846
4. Operational Availability (A_o)	
a. Incinerate and produce steam with solid waste (A_{o1})	0.792
b. Incinerate solid waste (A_{o2})	0.810
c. Produce steam without solid waste (A_{o3})	0.819
5. Mean-Time-To-Repair (MTTR), hours	10.0
6. Preventive Maintenance Ratio (PMR)	0.24
7. Corrective Maintenance Ratio (CMR)	0.06
8. Maintainability Index (MI)	0.30
9. Thermal-Efficiency (TE)	0.48
10. Specific Operating Man-hours (SOM)	0.315[1]
11. Specific Repair and Maintenance (SRM) Man-hours	0.031[1]
12. Specific Total Man-hours (STM)	0.345[1]
13. Specific Repair and Maintenance Cost (SRC)	\$0.26[2]
14. Specific Consumable Cost (SCC)	\$2.03[2]
15. Average Cost of Steam (ACS)	\$5.74[2]
[1] Labor hours per 10^6 Btu	
[2] Dollars per 10^6 Btu	

The demonstrated Mean-Time-Between-Failures (MTBF) for the entire HRI installation was 277 hours. This means that on the average one would expect to operate for 277 hours between consecutive failure-induced shutdowns.

The demonstrated Mean-Time-Between Maintenance Actions (MTBMA) for the entire HRI installation was 171 hours. This means that on the average one would expect to operate 171 hours and then require a maintenance action (i.e. to replace a failed item or unjam an item). Maintenance actions include all corrective actions whether or not a failure occurred.

The demonstrated Reliability (R) for the entire HRI installation was 0.648. This means that there is a 0.648 probability that the HRI will operate trouble-free for 120 consecutive hours (5 days at 24 hours) during a normal operation cycle.

The demonstrated operational availability (A_o) for the entire HRI installation was 0.792. This means that there is a 0.792 probability that the HRI will be capable of performing all of its functions when called upon at any random point in time.

There were 13 repairs, associated with HRI failures, that were used in the Mean-Time-To-Repair (MTTR) computations and that accounted for 130 calendar hours (216 corrective maintenance manhours). The demonstrated MTTR for HRI failures during this period was 10.0 hours.

This indicates that on the average, approximately 10 hours (more than a complete shift) were required to restore a failed condition. A brief discussion of each subsystem's maintenance problems follows.

1. Incineration Subsystem. MTTR = 11.3 hours (three failures)

Two of the three incinerator subsystem repair times were associated with the subsystem's hydraulics. Replacing a worn-out high pressure pump along with related maintenance (i.e. replacing O-rings and rod packing on nos. 1 and

2 ram cylinders, changing high pressure hoses and filters) required 16 hours; replacing a badly leaking rod seal packing of the stoker grate cylinder required 15 hours.

2. Processing Subsystem. MTTR = 7.3 hours (six failures)

This subsystem consists of the front-end loader, overhead crane, hopper, and incinerator ram feed. Five of the six subsystem failures were experienced by the overhead crane with repair times ranging from 4.8 to 11 hours. 55 percent of the total subsystem repair time was spent restoring overhead crane brake failures.

3. Boiler and Ash Removal Subsystems. MTTR = 16.7 and 2.5 (three and one failures, respectively).

The 16.7 hour MTTR for the boiler subsystem is heavily influenced by a 38 hour repair time to rewind and restore the ID fan motor. Without this failure the boiler subsystem MTTR would be 6.0 hours.

The Preventive Maintenance Ratio (PMR) during this period was 0.24. This means that for every twenty-four hours of operation, six man-hours are required for routine (preventive) maintenance. The PMR ratio is determined by dividing the man-hours spent on preventive maintenance by the total operating time. It is estimated by on-site personnel that only about 15 hours per week were spent on required routine maintenance (i.e. blowdown, cleanout of the secondary combustion chamber and fire tubes).

The Corrective Maintenance Ratio (CMR) was 0.06. This means that for every twenty-four hours of operation, only 1.4 man-hours are required for corrective maintenance. The CMR ratio is determined by dividing the man-hours spent on corrective maintenance by the total operating time.

The above rationale also holds true for the Maintainability Index (MI). The MI for the HRI installation was 0.30. This means that for every twenty-four hours of operation, seven man-hours are spent on corrective and preventive maintenance.

The overall Thermal-Efficiency for the HRI was 0.48. This means that for every Btu entering the HRI in the form of solid waste, kilowatt hours, and fuel oil; a little less than half a Btu was released in the form of steam. Thermal-Efficiency is determined by dividing the Btu output (steam produced) by the total amount of Btus supplied to the HRI. Sixty-eight percent of the Btu supplied to the HRI was derived from solid waste, another twenty percent was obtained from waste oil (which burns at 100 gph when solid waste is not being used). The remaining twelve percent was acquired from electrical power, makeup water, diesel fuel, and virgin oil resources.

In calculating the average cost of steam (equation 38), it is indicated that it cost $5.74 to produce 1,000,000 Btus of heat. This equation takes into account the cost of repair and replacement parts, consumable items (i.e., water treatment chemicals, fuel, etc.), and labor costs. Only direct labor costs were considered and were based on an estimate of $10.00 per hour. The $5.74 average cost of steam represents a $3.39 reduction from FY-81. This new value compares favorably to gross estimates taken from various Navy boiler plant Utility Cost Analysis Reports (UCARs) in which the average costs per MBtu were approximated at $10.00 for Navy Residual oil-fired (#6 fuel), $15.00 for distillate fuel-fired (#2), and $7.00 for natural gas.[1] Section III provides the computations of the parameters listed in table 3.

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[1]UCAR data taken from the boiler plants at the following locations: Naval Public Works Center (NPWC) Norfolk, VA, Bldg. P-1; NAS Oceana, VA; Navy Shipyard (NSPYD), Phila. PA; NAB Little Creek, VA; Washington Navy Yard, D.C.; NPWC Norfolk, VA Bldg. SP85; NAB Little Creek, VA; Phila. NSPYD, PA; NPWC Great Lakes, IL; NPWC Pensacola, FL; NSPYD Mare Is., CA.

Table 4. Long-Term Solid Waste Disposal Efficiency

1.	Processing rate of the HRI facility, in tons per hour	1.49
2.	Efficiency of steam production, in pounds of steam per pound of solid waste	3.09
3.	Efficiency of solid waste weight reduction through incineration	0.68
4.	Efficiency in reducing landfill (by weight) for solid waste accepted at HRI	0.64

The long-term solid waste disposal efficiency parameters are shown in table 4. Appendix A contains a breakdown of the data while the computations are contained in the technical discussion (Section D).

B. Comparison of FY-81 and FY-82 RAM Parameters

The overall HRI Mean-Time-Between-Failures (MTBF) for the first nine months of FY-82 revealed a 120 percent improvement (from 126 to 277 hours) over the twelve month FY-81 value. The most notable area of reliability growth was the ash removal subsystem where the number of reported failures declined from eight in FY-81 to one in FY-82.

The probability that the HRI will be capable of functioning when called upon (A_o) has increased thirty percentage points from approximately 0.5 to almost 0.8. This improvement in the HRI operational availability is attributed to the sharp reduction in corrective maintenance downtime (from 820 hours to 130 hours).

The HRI maintainability as measured by the Mean-Time-To-Repair has inflated from 8.2 to 10.0 hours. However, this change was most heavily influenced by a single failure (ID fan) which required 38 hours to repair as discussed previously.

Table 5. RAM Parameter Comparison (FY-81 and FY-82).

Parameter	FY-81	FY-82
Reliability (R)	0.386	0.648
(MTBF)	126	277
Availability (A_o)	0.489	0.792
Maintainability (MTTR)	8.2	10.0
(MTBMA)	89	171

C. HRI Reliability Growth Profile

The ash removal subsystem was most responsible for HRI reliability growth. Zero shear pin failures were experienced by the ash conveyor during the FY-82 reporting period as compared to nine the previous year. These shear pins provide a fuse-type function to hold the ash conveyor sprockets and shaft in a fixed relationship until sufficient force is exerted to cause shearing of the pin. They are designed to fail at a predetermined force (threshold) in order to protect the ash conveyor drive assembly components (i.e. motor and gearing). The improved reliability is attributed to greater scrutiny of the waste stream during hand-sorting operations on the tipping floor coupled with a reduction in the stoker speed. No hardware modifications were made during this period. Therefore, it is evidenced that a positive relationship exists between pre-incineration processing (handsorting or otherwise) efficiency and ash conveyor subsystem reliability. Extraction of non-combustible materials from the waste stream decreases the probability of jamming these items between the chain and sprocket assemblies.

While the failure frequency of waste receiving/incinerator feed equipment has remained relatively constant, the nature of these failures has changed considerably. The four FY-81 overhead crane failures consisted of three remote-control assembly problems and one clutch assembly problem. In contrast, three of the five crane failures encountered during this reporting period involved brake components (i.e. worn shoes, broken rivets, major adjustment). No repetitive part failures have been found. However, the initimate relationship between control-box and brake components cannot be ignored during failure troubleshooting. A faulty control-box spring (internal) may be overlooked if moderately worn brake shoes are prematurely blamed for braking failure.

Problems encountered by the incinerator feed ram hydraulics (four failures in FY-81) have not been repeated during the initial three quarters of FY-82. No apparent reason can be found for this improvement. The hydraulic-related failures experienced during FY-81 are believed to have been caused by heat-induced problems. The ram loader plate which travels through the bottom of the hopper has been warped due to the intense heat of the incinerator entrance area. Resultant deformation can increase the resistance to movement (friction) placing an additional load (stress) on hydraulic components. A second problem occurs when the ram is extended into the incinerator entrance area and remains fixed for any period of time. The hydraulic cylinder rod, which actuates the ram, is subjected to the conductive heat from the ram surface. When the rod retracts, it brings the heat into the cylinder which leads to failure of other hydraulic components (i.e. seals, O-rings).

Periodic recording of HRI reliability estimates (MTBF) provides a time sequence of data from which trends can be monitored. It also allows for the opportunity to extrapolate the curve beyond present values to determine whether or not reliability requirements can be met. Figure 1 contains a graphic presentation of the HRI reliability trend based upon quarterly data.

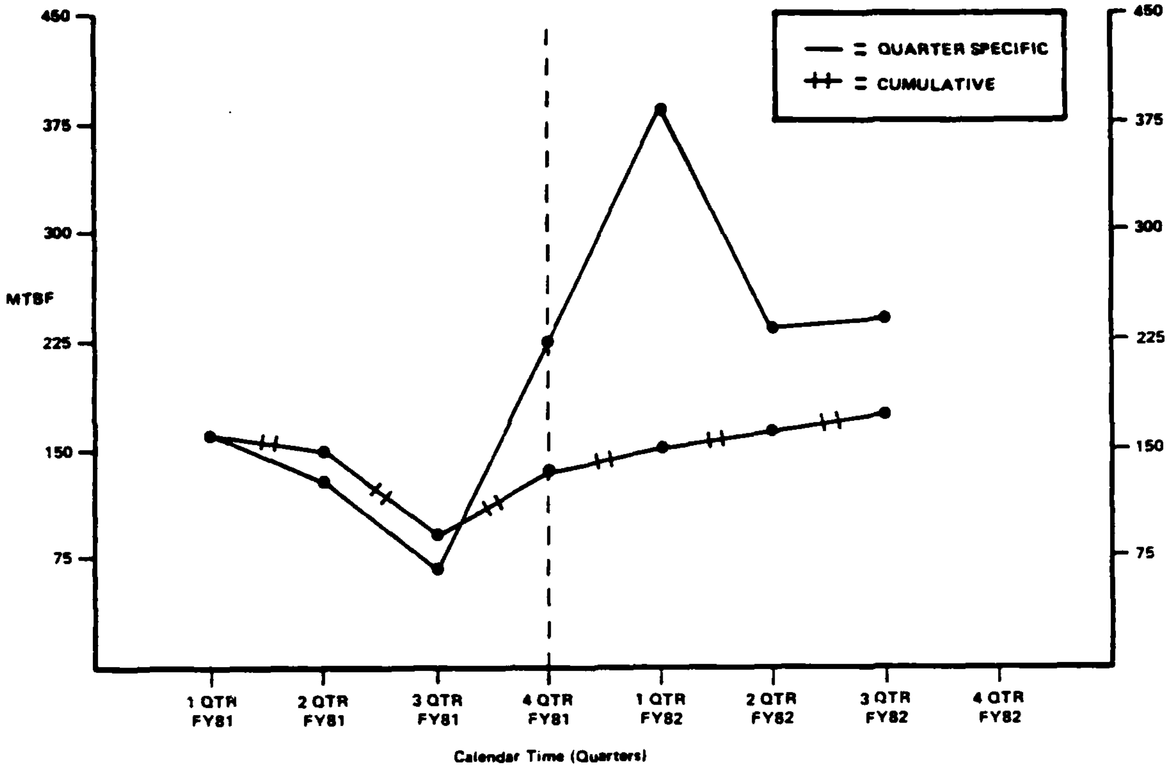

Figure 1. HRI Reliability Trend - Quarterly.

The "quarter-specific" trendline depicts HRI reliability trend when based upon three-month operating data. Being statistically more volatile than the cumulative trendline it indicates a sharp reliability improvement over the last four quarters. By contrast, each data point in the "cumulative" reliability trendline represents the sum of the data from the indicated quarter and each of the quarters prior to it. The cumulative reliability trendline implies a modest but steady reliability growth profile. Some reasons for this growth have been cited earlier. In addition, such factors as operating personnel experience, maintenance and replacement-parts quality, number and types of design changes, and system shakedown are believed to have contributed to this growth. No apparent causes can be found to explain the MTBF anomalies observed during 3rd Qtr FY-81 and 1st Qtr FY-82 other than the mathematical relationship between the operating time and the number of failures experienced. It was noticed however, that an uncharacteristically low amount of operating hours (69 hrs.) was accrued during 3FY-81 due to a large amount of idle-nonoperational time.

D. Long-Term Evaluation Findings and Predicted Values

A reliability parts-count prediction was previously performed as part of the overall reliability engineering analysis on HRI installations at Naval Station Mayport and Naval Air Station Jacksonville. The results were published by NCEL as CR82.032 "Reliability Engineering Analysis, Small-Scale Heat Recovery Incinerator Installations, August 1982." This report provides a predicted Mean-Time-Between-Failures (MTBF) of 457 hours for NS Mayport HRI.

In order to provide a rather confident point estimate of the HRI reliability the longterm evaluation data was divided into seven quarters. Since the prediction did not include certain parts which have contributed to observed failure (i.e. relief stack door and refractory, boiler hand hold plug, dearator tank, flight bars, damper pivot rod, crane gears) some failures have been discounted. From this seven quarterly MTBFs were generated and then averaged. The resulting MTBF was 283 hours (standard error = 57.7). In light of the reliability (MTBF) growth shown in figure 1 and the understanding that the parts count prediction is a rather gross (rough order of magnitude) estimate of inherent reliability, it appears that the true HRI reliability is not far from the expected/predicted value of 457 hours.

IV. DATA ANALYSIS

The calculations of the various parameters contained in table 3 of the Summary used the equations listed in reference 1. Additional manipulation of the data was required to provide the desired RAM, thermal-efficiency (TE), and cost parameters. All numbers used in RAM calculations can be obtained directly from the appendices; heating values of the various energy sources used in TE calculations were obtained from reference (2) and standard thermodynamics tables; and the numbers used in the cost-factor calculations were obtained from documents supplied by the HRI contractor and affiliated public works department. The following provide the rationale and computation of these parameters.

A. RAM

Three separate values of each reliability, maintainability (MTBMA), and availability (A_o) parameter were developed to represent the three primary missions of the HRI. The following equations were used to compute the RAM parameters based upon data extracted from Appendices A and B.

RAM Equations	Three-Quarter FY-82 Data	
1. $MTBF = \frac{t_a}{N_f}$	$MTBF_1 = \frac{3596.41}{13} = 277$ hours	(1)
where	$MTBF_2 = \frac{3596.41}{10} = 360$ hours	(2)
t_a = operating time for specific mission (hours)	$MTBF_3 = \frac{3596.41}{5} = 719$ hours	(3)
N_f = number of failures - See Table 2		
2. $MTBMA = \frac{t_a}{N_{ma}}$	$MTBMA_1 = \frac{3596.41}{21} = 171$ hours	(4)
where	$MTBMA_2 = \frac{3596.41}{16} = 225$ hours	(5)
t_a = operating time for specific mission (hours)	$MTBMA_3 = \frac{3596.41}{7} = 514$ hours	(6)
N_{ma} = number of maintenance actions - See Table 2		

RAM Equations	Three-Quarter FY-82 Data
3. $R = e^{-\lambda t}$	$R_1 = e^{-120/277} = 0.648$ (7)
where	$R_2 = e^{-120/360} = 0.717$ (8)
e = naperian base (2.718...)	$R_3 = e^{-120/719} = 0.846$ (9)
λ = failure rate for specific mission. $\lambda = 1/MTBF$	
t_m = mission time (120 hours)	
4. $A_o = \dfrac{t_a}{t_a + t_b + t_c + t_e}$	$A_{o1} = \dfrac{3596.41}{3596.41 + 316.79 + 130.30 + 498.87} = 0.792$ (10)
where	$A_{o2} = \dfrac{3248.92}{3248.92 + 316.79 + 80.03 + 365.03} = 0.810$ (11)
t_a = operating time for specific mission (hours) t_b = time spent in routine maintenance (hours)	$A_{o3} = \dfrac{3596.41}{3596.41 + 316.79 + 69.00 + 410.50} = 0.819$ (12)
t_c = corrective maintenance for specific mission t_e = idle, non-operational time for specific mission	
5. $MTTR = \dfrac{t_c}{N_r}$	$MTTR = \dfrac{130.3}{13} = 10.0$ hours (13)
where	
t_c = total active corrective maintenance time of repairs See Appendix A Table 1	
N_r = number of repairs	
6. $PMR = \dfrac{Mt_b}{t_a}$	$PMR = \dfrac{871}{3596} = 0.24$ (14)
where	
Mt_b = man-hours spent on routine maintenance	
t_a = total operating time	

RAM Equations	Three-Quarter FY-82 Data	
7. $CMR = \frac{Mt_c}{t_a}$	$CMR = \frac{216}{3596} = 0.06$	(15)

where

Mt_c = man-hours spent on corrective maintenance

t_a = total operating time

8. $MI = \frac{Mt_b + Mt_c}{t_a}$	$MI = \frac{1087}{3596} = 0.30$	(16)

where

t_a = total operating hours

Mt_b = man-hours spent on routine maintenance

Mt_c = man-hours spent on corrective maintenance

B. Long-term Thermal-Efficiency

The equation for long-term thermal-efficiency was taken directly from reference 1 and solved using the information from Appendix A.

$$TE = \frac{M_{15} \times h_s}{H_{hri}} = \frac{3.55 \times 10^{10} \text{ Btu}}{7.37 \times 10^{10} \text{ Btu}} = 0.48 \qquad (17)$$

where

TE = Thermal-efficiency

M_{15} = Steam generated, pounds

h_s = Heat of steam, Btu/pounds

H_{hri} = Btu supplied to HRI

H_{hri} is determined by the addition of the heat, in Btu, derived from the various energy resources supplied directly to the HRI or consumed indirectly. Equations 18-24 provide for the individual computation of heat from the various energy resources. In simplified form,

$$H_{hri} = H_{sw} + H_{vo} + H_{wo} + H_f + E_t + H_w \tag{18}$$

where

H_{sw} = Heat in Btus derived from solid waste and supplied to HRI

H_{vo} = Heat in Btus derived from virgin oil and supplied to HRI

H_{wo} = Heat in Btus derived from waste oil and supplied to HRI

H_f = Heat in Btus from fuel oil supplied to front-end loader

E_t = Electrical power in Btus supplied to the HRI

H_w = Thermal energy in Btus of the makeup water supplied to the HRI

<u>Efficiency Equations</u> <u>Three-Quarter FY-82 Data Base</u>

1. Heat derived from solid waste.

$$H_{sw} = (h_{sw})(M_{12}) = (5137 \text{ Btu/pound})(2000 \text{ pounds/ton})(4846 \text{ tons}) \tag{19}$$

$$= 4.979 \times 10^{10} \text{ Btu}$$

where

H_{sw} = Heat in Btu derived from solid waste and supplied to HRI.

h_{sw} = Heating value of solid waste in Btu/pound

M_{12} = Solid waste supplied to HRI in pounds

2. Heat derived from virgin oil.

$$H_{vo} = (h_{vo})(M_{20}) = (1 \text{ barrel/42 gallons})(5.83 \times 10^6 \text{Btu/barrel})(353 \text{ gallons})$$

$$= 4.899 \times 10^7 \text{ Btu} \tag{20}$$

where

H_{vo} = Heat in Btu derived from virgin oil and supplied to HRI

h_{vo} = Heating value of virgin oil in Btu/pound

M_{20} = Virgin oil supplied to HRI in pounds

3. Heat derived from waste oil.

$$H_{wo} = (h_{wo})(M_{21}) = (19{,}673 \text{ Btu/pound})(6.86 \text{ pound/gallon})(110{,}458 \text{ gallons})$$

$$= 1.491 \times 10^{10} \text{ Btu} \quad (21)$$

where

H_{wo} = Heat in Btu derived from waste oil and supplied to HRI

h_{wo} = Heating value of waste oil in Btu/pound

M_{21} = Waste oil supplied to HRI in pounds

4. Heat derived from front-end loader.

$$*H_f = (h_f)(M_{22}) = 0.016 \times 10^{10} \text{ Btu} \quad (22)$$

where

h_f = Heating value from fuel oil in Btu/pound

M_{22} = Fuel oil supplied to front-end loader in pounds

* Estimated value based on information given by plant personnel and same duty-cycle as FY-81 (fuel oil per ton of solid waste).

5. Energy equivalent of electrical power supplied to the HRI.

$$E_t = (e_t)(kWh/T_a)(T_a) =$$

$$= (11{,}600)(169.31)(3596) \quad (23)$$

$$= 0.706 \times 10^{10} \text{ Btu}$$

where

E_t = Electrical power in Btu supplied to the HRI

e_t = Conversion factor in Btu/kWh

T_{kwh} = Total kWh (kilowatt hours) supplied to the HRI

6. Thermal energy of makeup water supplied to the HRI.

$$H_w = (h_w)(M_{17}) = (48 \text{ Btu/pound})(8.3 \text{ pounds/gal})(4{,}227{,}250 \text{ gals}) \quad (24)$$

$$= 0.168 \times 10^{10} \text{ Btu}$$

where

H_w = Thermal energy in Btu of the makeup water supplied to the HRI

h_w = Heating value of water in Btu/pound

M_{17} = Makeup water supplied to HRI in pounds

The following provides the computation for H_{hri}:

$$H_{hri} = (4.979 \times 10^{10}\ \text{Btu}) + (0.004899 \times 10^{10}\ \text{Btu}) + (1.491 \times 10^{10}\ \text{Btu}) + (0.016 \times 10^{10}\ \text{Btu}) + (0.706 \times 10^{10}\ \text{Btu}) + (0.168 \times 10^{10}\ \text{Btu}) \quad (25)$$

$$= 7.37 \times 10^{10}\ \text{Btu}$$

C. Long-term Cost-Effectiveness

The equations for long-term cost-effectiveness were taken directly from reference 1 and solved using the information from Appendix A.

Cost Equations	Three-Quarter FY-82 Data

1. $$SOM = \frac{Mt_a \times 10^6}{M_{15} \times h_s} = \frac{1.1184 \times 10^{10}}{3.5531 \times 10^{10}} = 0.3148\ \text{man-hours}/10^6\ \text{Btu} \quad (26)$$

where

SOM = Specific Operating Man-hours

Mt_a = Man-hours of effort spent operating the HRI

M_{15} = Total amount of steam produced (pounds)

h_s = Heating value of the steam (Btu/pound)

2. $$SRM = \frac{(Mt_b + Mt_c + Mt_e) \times 10^6}{M_{15} \times h_s} = \frac{0.1087 \times 10^6}{3.5531 \times 10^{10}} \quad (27)$$

$$= 0.0306\ \text{man-hours}/10^6\ \text{Btu}$$

where

SRM = Specific Repair and Maintenance Man-hours

Mt_b = Man-hours of effort spent in preventive maintenance

Mt_c = Man-hours of effort spent in corrective maintenance

Mt_e = Man-hours of effort spent on the HRI during idle non-operational downtime (equal to zero for FY-81)

M_{15} = Total amount of steam produced (pounds)

h_s = Heating value of the steam (Btu/pound)

3. $STM = SOM + SRM = (0.3148 + 0.0306)$ (28)

$= 0.3454$ man-hours/10^6 Btu

where

STM = Specific Total Man-hours

4. $$SRC = \frac{(CP)(10^6)}{M_{15} \times h_s} = \frac{\$9,113.51 \times 10^6}{3.5531 \times 10^{10}} = \$0.26/10^6 \text{ Btu} \qquad (29)$$

where

SRC = Specific Repair and Maintenance Cost

CP = Total cost of parts used in repairs/replacements and maintenance

M_{15} = Total amount of steam produced (pounds)

h_s = Heating value of steam (Btu/pound)

5. $$SCC = \frac{(CF + CC)(10^6)}{M_{15} \times h_s} = \frac{\$73,091 \times 10^6}{3.5531 \times 10^{10}} = \$2.06/10^6 \text{ Btu} \qquad (30)$$

where

SCC = Specific Consumable Costs

CF = Total cost of fuel used (virgin and waste oil, diesel and electrical power)

CC = Total cost of consumable supplies not included in CF

M_{15} = Total amount of steam produced (pounds)

h_s = Heating value of the steam (Btu/pound)

The breakdown in costs and quantities used for the nine month operation is as follows:

(1) Water treatment chemicals

$$\text{Salt} = (21{,}890 \text{ pounds})(\$2.60/80 \text{ pounds}) = \$\ 711 \quad (31)$$

$$PO_4 = (570 \text{ pounds})(\$50.64/100 \text{ pounds}) = \$\ 289 \quad (32)$$

$$SO_3 = (567 \text{ pounds})(\$29.36/100 \text{ pounds}) = \$\ 166 \quad (33)$$

Subtotal $1166

(2) Electrical power

1 kWh = 11,600 Btu
1 kWh = $ 0.06

$$E_T = \$36{,}463 \quad (34)$$

(3) Waste oil

110,458 gallons consumed @ $0.30/gallon

$$\text{cost for waste oil} = (110{,}458 \text{ gallons})(\$0.30/\text{gallon}) = \$33{,}137 \quad (35)$$

(4) Virgin oil

353 gallons consumed @ $1.12/gallon

$$\text{Cost for virgin oil} = (353 \text{ gallons})(\$1.12/\text{gallon}) = \$395 \quad (36)$$

(5) Diesel fuel

879 gallons consumed @ $1.22/gallon

$$\text{Cost for diesel fuel} = (879 \text{ gallons})(\$1.22/\text{gallon}) = \$1072 \quad (37)$$

(6) Other consumables (i.e. hydraulic fluid, refractory)

Cost estimated at $858

(7) Total

The cost total of (1) thru (6) is $73,091

6. $ACS = SRC + SCC + (STM \times W)$ (38)

$= 0.026 + 2.03 + 0.3454 \times 10 \approx \$5.54/10^6$ Btu

where

ACS = Average Cost of Steam

SRC = Specific Repairs and Maintenance Cost

SCC = Specific Consumable Cost

STM = Specific Total Man-hours

W = Wages in dollars per hour (based on an estimate derived from public works job orders of $10/hr.)

D. Long-term Solid Waste Disposal Efficiency

The efficiency of the HRI facility to reduce the volume of solid waste that would otherwise be delivered to the landfill and to produce steam will be determined by the following equations.

1. $PR = \frac{M_{12}}{t_{a'}} = \frac{4846}{3249} = 1.49$ (39)

where:

PR = Processing rate of the HRI facility, in tons per hour of operation

M_{12} = Solid waste burned in the HRI, in tons

$t_{a'}$ = Processing equipment operation time, in hours

2. $SP = \frac{M_{15}}{M_{12}} = \frac{29,933,846}{9,692,000} = 3.09$ (40)

where

SP = Efficiency of steam production, in pounds of steam per pound of solid waste

M_{12} = Solid waste supplied to HRI, in pounds

M_{15} = Steam produced, in pounds

3. $$DR = \frac{M_{12} - M_{14}}{M_{12}} = \frac{6,600,000}{9,692,000} = 0.68 \qquad (41)$$

where

DR = Efficiency of solid waste weight reduction through incineration.

M_{12} = Solid waste burned in the HRI, in pounds

M_{14} = Wet ash removed, in pounds

In analyzing the long-term cost-effectiveness, the incineration process and the production of steam were considered together. From October 81 to June 82, the total amount of solid waste delivered to the plant was 10,318,000 pounds. The total sent back to the landfill was 3,756,000 pounds. Therefore, the percentage of landfill reduction (PLR) for this period was:

$$PLR = 100 \times 1 - \frac{(M_3 + M_{14} + M_a)}{M_3 + M_1} = 100 \times [1 - \frac{3,756,000}{10,318,000}] = 64 \qquad (42)$$

where

M_3 = Amount of solid waste rejected by hand, in tons

M_1 = Amount of solid waste incinerated, in tons

M_a = Amount of fly ash removed by the dust filter, in tons

M_{14} = Amount of wet ash removed, in tons

The amount of waste delivered to the HRI minus the amount of waste taken from the HRI provides a gross index for landfill savings accomplished by incineration. This number was 3281 tons for the nine-month period.

E. Time Categories

During the evaluation and extraction of data, manipulation of the reported time categories was required to provide the proper increments of time necessary to compute the various RAM parameters. This was particularly true during periods of downtime when both corrective and preventive (routine) maintenance was performed. The reported data did not always indicate when preventive or corrective maintenance started and stopped during long periods of shutdown. It was often implied that the entire day (i.e. 24 hours) was spent performing both corrective and preventive maintenance. The data from such scenarios were modified using the following criteria. It was estimated that 10 hours out of each 24-hour downtime cycle were spent on actual corrective maintenance (t_c) and the remaining 14 hours were logged under t_e, which indicates that the HRI is idle, but not operational. The resulting time categories are reflected in table A-1 (Appendix A). This technique provides the desired sensitivity to ensure more realistic RAM data.

During these lengthy shutdowns for corrective maintenance the three shifts performed preventive maintenance of the nature that was desirable, but not required. The logs showed that preventive maintenance was performed during these shutdown periods. To correctly solve the time equation for the HRI operation, given in reference 1 and listed below, the time categories cannot overlap. Therefore, when the system was shutdown for corrective maintenance and some preventive maintenance was performed concurrently, the time was charged only to corrective maintenance.

$$T = t_a + t_b + t_c + t_d + t_e = 6552 \text{ hours}$$

where:

- T - Nine month HRI monitoring period
- t_a - Operating period, hours
- t_b - Calendar time spent on routine maintenance
- t_c - Calendar time spent on repairs/replacement
- t_d - Idle time, HRI operational (but not used)
- t_e - Idle time, HRI not operational

ACRONYM/NOMENCLATURE LIST

A_o	-	Operational availability (see equations 10-12)
CC	-	Total cost of consumable supplies not included in CF
CF	-	Total cost of fuel used (virgin and waste oil, diesel, and electrical power)
CMR	-	Corrective Maintenance Ratio (see equation 15)
CP	-	Total cost of parts used in repair, maintenance, and replacement
DR	-	Efficiency of solid waste weight reduction through incineration (see equation 41)
E_t	-	Electrical power in Btus supplied to the HRI (see equation 23)
e	-	Base of Naperian log system (2.718)
FY-82	-	Fiscal Year 1982
HRI	-	Heat Recovery Incinerator
H_f	-	Heat in Btus from fuel oil supplied to front-end loader (see equation 22)
H_{hri}	-	Btus supplied to HRI (see equations 18 through 25)
H_{sw}	-	Heat in Btus derived from solid waste and supplied to HRI (see equation 19)
H_{vo}	-	Heat in Btus derived from waste oil and supplied to HRI (see equation 20)
H_w	-	Thermal energy in Btus of the makeup water supplied to the HRI (see equation 24)
H_{wo}	-	Heat in Btus derived from waste oil and supplied to the HRI (see equation 21)
h_f	-	Heating value from fuel oil in Btu/pound
h_{sw}	-	Heating value from solid waste in Btu/pound
h_{vo}	-	Heating value from virgin oil in Btu/pound
h_w	-	Heating value of water in Btu/pound
h_{wo}	-	Heating value of waste oil in Btu/pound

ACRONYM/NOMENCLATURE LIST (Continued)

h_s - Average total heat of steam produced by the HRI, Btu/pound

M_1 - Amount of solid waste arriving at the HRI facility, tons

M_3 - Amount of solid waste that is hand-rejected, tons

M_{12} - Solid waste supplied to HRI, pounds (M_1 - M_3)

M_{13} - Amount of fuel and waste oil, pounds

M_{14} - Wet ash removed, pounds

M_{15} - Steam produced over the monitoring period, pounds

M_{17} - Makeup water supplied to HRI, pounds

M_{19} - Blowdown, pounds

M_{20} - Virgin oil supplied to HRI, pounds

M_{21} - Waste oil supplied to HRI, pounds

M_{22} - Fuel oil supplied to front-end loader, pounds

MI - Maintainability Index (see equation 6)

Mt_a - Man-hours of effort spent on the HRI during the period t_a

Mt_b - Man-hours of effort spent on the HRI during the period t_b

Mt_c - Man-hours of effort spent on the HRI during the period t_c

Mt_d - Man-hours of effort spent on the HRI during the period t_d

Mt_e - Man-hours of effort spent on the HRI during the period t_e

MTBF - Mean-Time-Between-Failures, hours (see equations 1 through 3)

$MTBF_{as}$ - Mean-Time-Between-Failures, ash handling subsystem (see equation 2)

$MTBF_{bs}$ - Mean-Time-Between-Failures, boiler subsystem (see equation 3)

$MTBF_{hri}$ - Mean-Time-Between-Failures, heat recovery incinerator (see equation 1)

$MTBF_{ht}$ - Mean-Time-Between-Failures, heat transfer network

$MTBF_{is}$ - Mean-Time-Between-Failures, incinerator subsystem

ACRONYM/NOMENCLATURE LIST (Continued)

$MTBF_{ps}$ - Mean-Time-Between-Failures, processing subsystem

$MTBF_{rs}$ - Mean-Time-Between-Failures, receiving subsystem

MTTR - Mean-Time-To-Repair, hours (see equation 7)

MTBMA - Mean-Time-Between-Maintenance Action, hours (see equations 4-6)

NAS - Naval Air Station

NCEL - Naval Civil Engineering Laboratory

N_f - Number of failures that caused shutdown of the HRI or subsystem

N_{ma} - Number of maintenance actions

N_r - Number of repairs

NS - Naval Station

PC - Processing capacity of the HRI facility in tons per hour (see equation 25)

PLR - Percent Landfill reduction (by weight) for solid waste accepted at HRI.

PMR - Preventive Maintenance Ratio (see equation 4)

R - Reliability as a probability (expressed as a decimal)

RAM - Reliability, Availability, and Maintainability

RCRA - Resource Conservation Recovery Act

Rp - Total active repair time spent on corrective maintenance

SCC - Specific Consumable Costs (see equation 30)

SOM - Specific Operating Man-hours (see equation 26)

SP - Efficiencies of steam production in terms of pounds of steam per pounds of solid waste (see equation 40)

SRM - Specific Repairs and Maintenance Man-hours (see equation 27)

STM - Specific Total Man-hours (see equation 28)

T - Total monitoring period, hours

T_{kwh} - Total kilowatt hours supplied to the HRI

T_E - Overall thermal efficiency (see equation 17)

t_a - HRI operating period, hours

$t_{a'}$ - Processing equipment operating period, hours

t_b - Time spent in routine maintenance, can be calendar or total time, hours

t_c - Time spent in repairs/replacements, can be calendar or total time, hours

t_d - HRI idle time (operational), hours

t_e - HRI idle time (not operational), hours

t_m - Mission time for Reliability calculations, hours

W - Wages in dollars per hour

APPENDIX A

MONTHLY SUMMARIES OF

NS MAYPORT HRI DATA

(FISCAL YEAR 1982)

Table A-1. Breakdown of Hours and Manhours.

Month	t_a	t_b	t_c	t_d	t_e	M_{ta}	M_{tb}	M_{tc}
October	369.65	20.0	19.8	175.74	134.37	1200	30	81
November	343.32	50.5	0.0	321.18	4.0	926	182	0
December	465.26	25.0	3.0	238.83	8.0	1480	53	7
January	313.74	57.5	17.0	337.58	13.15	1022	194	44
February	419.50	27.0	38.0	84.17	102.35	1104	118	8
March	440.57	70.8	13.5	104.57	115.33	1312	169	32
April	433.49	12.0	27.0	178.66	79.75	1580	22	31
May	423.74	35.0	3.0	279.33	4.0	1280	67	6
June	387.14	19.0	9.0	183.66	37.92	1280	36	6
Totals	3596.4	316.8	130.3	1903.7	498.9	11184	871	216

t_a - hours of boiler operation

t_b - hours spent on routine maintenance

t_c - hours spent on corrective maintenance

t_d - hours HRI is idle, but operational

t_e - hours HRI is idle, but not operational

M_{ta} - man-hours spent in operation

M_{tb} - man-hours spent on routine maintenance

M_{tc} - man-hours spent on corrective maintenance

Table A-2. Energy Resources Consumed, Rejected, and Steam Outputs.

Month	M_{13}	M_{17}	M_{19}	M_1	M_3	M_{14}	M_a	M_{15}
October	7870	462350	39320	674.56	59380	412180	2310	3543391
November	11821	378700	51150	448.47	62530	278630	4980	2760608
December	13273	544100	77160	696.67	88040	485078	6710	3938873
January	16646	360700	57570	298.57	28620	200440	4200	2563186
February	12076	516200	86560	640.11	99260	411580	2460	363991
March	13067	487300	96000	472.98	62460	328100	5720	3326510
April	16072	537300	113440	566.01	86300	310860	4060	3611059
May	8508	493000	103750	699.55	94260	471390	4520	3315850
June	12478	447600	63864	358.38	45760	194000	3480	3237377
Totals	110811	4227250	688814	4846	626610	3092258	38440	29933846

M_{13} - auxillary fuel, gallons

M_{17} - makeup water, gallons

M_{19} - blowdown, gallons

M_1 - solid waste incinerated, tons

M_3 - rejected solid waste, pounds

M_{14} - wet ash, pounds

M_a - fly ash, pounds

M_{15} - steam produced, pounds

APPENDIX B

SUMMARY OF NS MAYPORT

HRI FAILURES/MAINTENANCE ACTIONS

(FISCAL YEAR 1982)

This appendix contains a composite listing (Table B-1) of the failures and maintenance actions reported during the first nine months of FY-82. Each problem event is assessed to one of four equipment group (subsystem) categories; boiler equipment, incinerator-equipment, ash removal equipment, and processing-equipment. Table B-1 also provides the date of occurrence, failed equipment/part information, and an event reference number.

Table B-1. HRI Problem Event Summary.

Event Reference Number	Date	Class	Subsystem (Code)	Failed Equipment/Part
F28	811009	F	I	Stoker, rod seal
M12	811009	MA	P	Crane, brake adjustment
F29	811028	F	P	Crane, brake shoes
M13	811109	MA	B	DM-3 bearings; feed pump shaft
F30	811213	F	I	DM-4, flapper pivot rod
M14	811218	MA	I	Stoker, rod seal leak
M15	820118	MA	P	Ram, packing rod seal leak
F31	820125	F	P	Crane, drive gears
F32	820126	F	B	D.A. Tank, WLC solenoid valve
M16	820206	MA	I	Stoker jammed
F33	820212	F	B	I.D. fan, motor winding
F34	820307	F	P	Crane, brake rivets
M17	820322	MA	B	Boiler refractory
F35	820322	F	A	Conveyor, flight bar
M18	820328	MA	I	Stoker jammed
F36	820405	F	P	Crane, track collector shoes
F37	820423	F	I	High pressure pump, valve
F38	820430	F	B	Feed pump no. 1
F39	820514	F	P	Ram control panel, relay
M19	820602	MA	I	Stoker jammed
F40	820622	F	P	Crane, brake shoes

LEGEND

Date: Year Month Day (two digits each)
Class: F = Failure
MA = Maintenance Action

Subsystem: P = Processing
I = Incinerator
A = Ash Removal
B - Boiler

DATE
ILME