DESTRUCTION EFFICIENCY OF MICROBIOLOGICAL ORGANISMS IN MEDICAL WASTE INCINERATORS: A REVIEW OF AVAILABLE DATA

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ABSTRACT

After a building has undergone a terrorist attack using a biological weapon such as B. Anthracis, many of the interior building materials will need to be disposed. Although it is likely that these materials will be decontaminated prior to their removal, officials may decide to remove the potentially bio-contaminated materials without first fumigating them. In either scenario, the possibility exists that some of the building materials will retain viable contaminating agent spores. Incineration may be the best option for the disposal of such building materials to completely destroy all potentially remaining bio-contaminants. In the early 1990s, the US Environmental Protection Agency (EPA) conducted microbial survivability tests at several medical waste incinerators (MWIs); these data have now been examined to evaluate microbiological destruction performance. Microorganisms were spiked into the waste feed and in test pipes, and subsequently analyzed for viability in the emissions, residue, and pipes using EPA conditional test methods. The results showed that for the most of the test runs, at least a five log reduction of the spores was achieved, although viable spores were detected in 10 out of a total of 48 air emission test runs, and spores were detected in 10 out of 27 available ash samples.

INTRODUCTION

In September, 2001, B. Anthracis spores were sent through the US Postal Service to various locations in Florida, New Jersey, New York, and Washington, D.C. Twenty-two cases of anthrax infection (or suspected infection) resulted in five deaths (1). In the Washington D.C. area, the interior of the buildings where spores were discovered were decontaminated with chlorine dioxide and other techniques (2). Although it is likely that these interior materials were completely decontaminated, the possibility exists that trace amounts of B. Anthracis spores remained viable. In addition, some interior building materials exposed to B. Anthracis spores may be removed without first being fumigated, and therefore could have a relatively high level of spore contamination.

The majority of the resulting decontamination waste (debris, solid waste, and personal protective equipment) from the Capitol area was disposed of in the MWIs located at Fort Detrick's U.S. Army Medical Research Institute of Infectious Diseases in Maryland. Officials decided to use the MWIs because B. Anthracis-contaminated materials were classified as medical waste in Washington, D.C. and Maryland. The classification of the waste (solid waste, hazardous waste, or medical waste) determines what disposal options are available, and can vary from state to state. From a technical standpoint, the MWIs were selected because they employed a batch process with higher gas temperatures and longer residence times than a typical continuous feed MWI (2). Based on the knowledge gained from the Capitol area waste disposal operation, incineration will likely continue to be the method of choice for disposal of at least some of the waste materials in any future bio-terrorist events.

There are no federal standards to ensure the complete destruction of microorganisms when disposing of medical waste in incinerators. Similarly, there are minimal data and literature available on the thermal destruction of microorganisms in an incinerator. This lack of standards and data is due to the conventional wisdom that all microorganisms should be destroyed in the high-temperature environment of an incinerator. However, for various technical reasons, it is conceivable that some of the

microorganisms in the waste feed may not be completely destroyed and may be emitted out the exhaust stack or remain viable in the residue (3). In one paper, Allen, R. J., et al. (4) reported that incineration of a surrogate waste in a hospital incinerator spiked with Bacillus subtilis resulted in no viable Bacillus subtilis in the stack-gas samples. However, viable bacteria other than Bacillus subtilis were found in stack gas samples, and it was suggested that these bacteria entered the incinerator via the indoor air inlet of the secondary combustion chamber.

The vast majority of the microbial destruction data available comes as a result of emissions tests conducted on full-scale MWIs by the EPA Office of Air Quality Planning and Standards and the EPA Office of Solid Waste in the early 1990s (5 – 12). These tests were conducted primarily to collect both criteria and hazardous air pollutant data in support of developing emission standards and to comply with the Medical Waste Tracking Act of 1988. However, the microbial survivability data from these EPA test reports have never been summarized and published in a public document or scientific paper. In light of the need to ensure complete destruction of B. Anthracis spores in incinerators, these data have now been reviewed to evaluate incinerator microbiological destruction performance and are presented here.

DESCRIPTION OF FACILITY INFORMATION AND DATA

The emission test reports were thoroughly reviewed and all microbial survivability data, incinerator operational data, test methods, quality control procedures and results, and other related information were extracted and logged into a spreadsheet. The data reported in the following tables are as they were reported in the test reports, except for the conversion of some of the data to SI units, and the reporting of some average levels. Table I is a summary of the MWI facilities that were tested. Table II is a summary of the MWI operational data for the time period during testing or for that day of testing. The test reports included detailed narrative descriptions of the process operation during the test as well as the operational data.

Table I Summary of Facility Information

Facility	Location	Date of test	Air pollution control	Incinerator type/description	Capacity
1	Sanford, NC	Sep-90	none	Controlled air; Manual charge, batch operation. Gas-fired primary and secondary chambers.	79 kg/hr pathological (path.) waste; 113 kg/hr med waste
2	Wilmington, NC	Aug-90	none	Joy Energy Systems, ram fed. Primary comb. chamber 3.85 m^3 starved air, NG fired; secondary chamber 2.4 m^3 w/ 1 sec gas res. time.	147 kg/hr of waste at 19,796 kJ/kg. Both red bag (infectious) and non-infect. burned.
3	Plymouth, MA	Mar-91	heat exchanger and spray cooling, followed by baghouse, then horizontal cross-flow packed bed absorber using NaOH	Simonds batch burn manual charge; Starved air. Primary chamber natural gas (NG) fired, 6 m^3. Secondary chamber gas fired, 1.16 sec res. time at 1600 F	340 kg/batch Type 0-4 (red bag, including path.) waste.
4	Kinston, NC	Mar-91	None	Joy Energy ram feeder; Starved air. Primary chamber NG fired, 3.85 m^3. Secondary chamber gas fired, 0.4 sec design res. time	145 kg/hr (19,796 kJ/kg)
5	Kalamazoo, MI	Apr-90	baghouse w/ dry lime injection.	3 chamber, starved air. 2nd chamber vol. 1.1 m^3 (res. time = 0.3 s), with burner. 3rd chamber vol. 2.8 m^3 (res time = 1.24 s) with no burner. With waste heat boiler	~ 295 kg/hr
6	Ann Arbor, MI	Jun-90	variable throat venturi wet scrubber followed by two packed bed absorbers (in series; caustic solution)	3 chamber, continuous feed, pulsed hearth, w/ waste heat boiler. 1st chamber vol = 25.4 m^3. 2nd and 3rd chamber vol combined = 16.5 m^3,	~ 408 kg/hr
7	Morristown, NJ	Nov-91	lime spray dryer, fabric filter.	ThermAll NG-fired rotary kiln (8 m long, 2.7 m dia), automatic ram feed, with after burner (18.7 m^3, 2 sec gas res. time) and waste heat recovery boiler	454 kg/hr; only permitted for 363 kg/hr

Table II Summary of MWI Operational Parameters During Testing

Test run	Date	Waste type	Avg. Feed rate (kg/hr)	Total feed charged (kg/day)	Ash (kg/day)	Avg. primary chamber temp (C)	Avg. second. chamber temp (C)	Avg. gas res. time in second chamber (s)	Avg. exhaust flow rate (actual m^3/min)	Avg. flue gas temp (C)	Avg. stack O2 level (% vol. Dry)
Facility 1											
1	9/20/90	pathological	48	229	10	770	807	0.12	69	400	15.8
2	9/21/90	general	74	462	63	758	946	0.11	64	432	15.7
3	9/22/90	pathological	54	267	10	815	815	0.13	62	404	16.1
4	9/23/90	general	70	411	78	846	858	0.11	67	415	15.2
5	9/24/90	pathological	77	307	20	784	805	0.12	69	397	15.6
6	9/25/90	pathological	65	317	19	772	794	0.12	63	385	15.7
8	9/27/90	general	73	330	62	792	922	0.11	67	408	15.6
9	9/28/90	pathological	76	394	35	785	828	0.11	72	411	15.3
10	10/2/90	pathological	45	206	8	785	801	0.12	64	398	15.7
Facility 2											
1	8/15/90	mixed*	80	558	24	1029	1104	0.92	116	758	8.5
2	8/18/90	mixed*	76	908	NA	1087	1142	1.05	100	773	7.2
3	8/19/90	mixed*	96	704	55	1014	1115	0.98	113	808	9.4
4	8/20/90	mixed*	121	593	96	863	1070	0.79	142	783	7.7
5	8/21/90	mixed*	88	412	63	877	1001	0.81	145	775	9.2
6	8/22/90	mixed*	87	530	42	854	987	0.83	140	758	9.8
7	8/26/90	mixed*	135	612	54	912	892	1.05	110	672	11.8
8	8/27/90	mixed*	132	567	50	892	909	1.10	105	687	9.3
9	8/28/90	mixed*	138	628	47	904	913	1.14	102	701	9
* both infectious and non-infectious waste											
Facility 3											
1	3/5/91	red bag	NA	327	32	345	976	1.45	78	633	8.8
2	3/5/19	red bag	NA			647	1019	1.52	69	594	8.8
3	3/7/19	red bag	NA	319	43	316	976	1.67	69	653	9.6
4	3/7/19	red bag	NA			652	1008	1.91	57	622	10.3
5	3/9/19	red bag	NA	331	27	338	982	1.77	63	623	11.2
6	3/9/19	red bag	NA			647	1050	2.16	51	663	8.6
tests 1, 3, and 5 were conducted during "burn" conditions (primary chamber at low flow air, sec chamb maintains setpoint temp)											
tests 2, 4, and 6 were conducted during "burndown" conditons (follows burn condition on same day;											
1	5/30/90	mixed	100	NA	129	973	964	0.32	125	698	10.9
2	5/31/90	mixed	114	NA	81	1049	999	0.31	127	727	10.1
3	6/1/90	mixed	134	NA	68	964	973	0.30	136	727	14.3
4	6/2/90	mixed	87	NA	59	818	880	NA	NA		11.4
4R	6/4/90	mixed	86	NA	85	983	966	0.33	121	694	14.1
6	6/5/90	mixed	86	NA	66	853	904	0.36	114	679	12
7	6/6/90	mixed	121	NA	111	1005	916	0.36	116	711	12.9
5R	6/6/90	mixed	89	NA		985	973	0.32	126	711	13.9
8	6/7/90	mixed	135	NA	66	1010	894	0.35	119	687	14.6
9	6/8/90	mixed	130	NA	86	993	903	0.36	117	698	13.1
Note: Run 5 invaldated and therefore repeated (R); Run 4 repeated because the PM/metals test invalid											
Facility 5											
MB3-1	5/5/90	G500	216	NA	NA	706	877	901*	37.1	179	11.7
MB3-2	5/7/90	G500	192	NA	NA	703	887	896*	39.8	181	11.8
MB3-3	5/8/90	G500	183	NA	NA	716	879	889*	38.2	178	12
MB1-1	5/23/90	G500	238	NA	NA	688	1016	1005*	45.8	178	13
MB1-2	5/24/90	G500	223	NA	NA	707	996	989*	41.0	174	12.1
MB1-3	5/31/90	G500	250	NA	NA	693	1019	1001*	41.8	186	13.1
EB1-1	5/17/90	G500	258	NA	NA	700	1125	1101*	43.0	177	12
EB1-2	5/18/90	G500	269	NA	NA	693	1128	1104*	43.6	185	12.1
EB1-3	5/21/90	G500	283	NA	NA	689	1131	1096*	45.0	179	11.2
* Tertiary chamber temperature (C)											
Facility 6											
1	6/23/90	general	358	NA	NA	941	1116	946*	NA	NA	NA
2	6/25/90	general	test was aborted								
3	6/25/90	general	395	NA	NA	943	1130	983*	NA	NA	NA
4	6/26/90	general	395	NA	NA	996	1129	982*	NA	NA	NA
5	6/28/90	general	384	NA	NA	906	1144	984*	NA	NA	NA
Note: flow rate and O2 level not available for individual runs, but average for all runs as follows: flow rate =126.5 dscmm;											
* Tertiary chamber temperature (C)											
Facility 7											
1	11/18/91	mixed	329	NA	NA	802	981	NA	99.5*	212	11.1
2	11/19/91	mixed	334	NA	NA	792	976	NA	96.7*	211	11.1
3	11/20/91	mixed	359	NA	NA	784	975	NA	102*	210	10.6
* flow rate dry standard			NA=	not avail							

RESULTS AND DISCUSSION

Table III is a summary of the microbial survivability data for the ash and emissions samples. The test methods that were used are described in detail elsewhere (13, 14), and are summarized as follows. In a typical test, a known number of spores - B. Stearothermophilus, a heat resistant microorganism used as a worst-case surrogate bacterium - was spiked with the waste feed at certain intervals throughout the emissions test. Emission samples were collected isokinetically following the secondary combustion chamber, i.e., prior to any air pollution control device, in a buffered solution in impingers. Ash samples (for most of the tests) were taken the day after each test. The recovered samples were cultured and colonies of B. stearothermophilus were identified and quantified. Table III shows that viable spores were detected in the flue gas in 10 of 48 air emission test runs, and in 10 of 27 available ash samples. For facilities 1 to 4, where both ash and air samples were taken and detection limits presented, the log reduction in spores ranged from 1.8 to greater than 8.2.

As discussed by Lemieux, et al. (3), there are several reasons that MWIs may not completely destroy all of the spiked microorganisms, including in-bed mass transfer limitations, incomplete bed mixing, bypassing of hot zones due to poor gas phase mixing, dropping through the grate prior to destruction in the bed, or by coming into contact with cool zones within the MWI. Coupled with complex fluid dynamics, these limitations would cause pockets within the combustion chambers that are not exposed to sufficiently high temperatures and residence times.

Another explanation is that all of the spiked spores were destroyed but the spores detected were another bacterium. Although the method used to collect the data presented in this paper includes analytical steps to generally assure that the colonies are B. stearothermophilus, the method does not identify each and every colony. Additional contamination may have occurred, such as in the handling of the sampling train, as indicated by the quality control program that EPA implemented during these tests. Out of approximately 30 field blanks (impingers) taken during the testing at 5 out of the 7 facilities, spores were detected in 3.

Some of the data may be false negatives or may be biased high or low, depending on how "non-detects" are handled and reported. Although no spores were detected in the flue gas for the majority of the test runs, this may be due to the high detection limit (~ 10,000 total spores), which is based on 1 spore per sample aliquot, aliquot volume, and gas sample volume. It is conceivable that spores were present in the stack gas but went undetected due to these high detection limits. It should be noted that if spores were indeed completely destroyed, but the reported amount is based on the detection limit, this would be a source of high bias. Finally, the data are based on the questionable assumption that no spores are found in the flue gas once sampling is completed. It may be possible that some of the spiked spores surviving the incinerator environment may not become entrained in the exhaust gas until after flue gas sampling has been completed.

Table IV shows the results for the microorganism survivability pipe tests. The pipe tests were performed as another technique for assessing microorganism survivability in the MWI residue. These pipes were charged with between 10^5 to 10^8 spores. Refer to EPA Conditional Test Method 25 for further details regarding this test procedure (13, 14). Note that out of 163 total pipes that were recovered from the MWIs, there were 59 pipes with spores that were detected or too numerous to count. In one test where internal pipe temperatures were measured, there were several pipes with spores surviving internal pipe temperatures above 816°C (7).

Table III Summary of Test Results for Microbial Survivability in Emissions and Ash

Facility	test run	date	total # spores spiked with waste feed	total # spores emitted in flue gas	total # spores in ash	log reduction	spore survivability (%)
1	1	9/20/1990	6.00E+12	ND < 3.8E4	ND <9.6E5	>6.8	<1.7E-5
1	2	9/21/1990	6.00E+12	ND <4.4E4	ND <6.3E6	>6.0	<1.1E-5
1	3	9/22/1990	6.00E+12	1.38E+07	ND <1.0E6	5.7	2.30E-04
1	4	9/23/1990	6.00E+12	ND <4.31E4	ND <7.8E6	>5.9	<1.3E-4
1	5	9/24/1990	6.00E+12	<13.5E6	ND <1.0E4	>5.6	<2.3E-4
1	6	9/25/1990	6.00E+12	1.85E+06	ND <1.9E6	6.5	3.10E-05
1	8	9/27/1990	6.00E+12	>15.5E6	ND <6.2E6	<5.6	>2.6E-4
1	9	9/28/1990	6.00E+12	6.94E+06	ND <1.8E4	5.9	1.20E-04
1	10	10/2/1990	6.00E+12	ND <3.22E4	ND <3.9E3	>8.2	<6.0E-7
2	1	8/15/1990	1.54E+12	ND <2.57E4	5.20E+07	4.5	3.30E-03
2	2	8/18/1990	1.54E+12	1.28E+05	NA	7.1	8.30E-06
2	3	8/19/1990	1.54E+12	ND <5.2E4	ND <2.7E4	>7.3	ND <5.1E-6
2	4	8/20/1990	1.54E+12	1.05E+05	ND <4.8E4	7.2	6.80E-06
2	5	8/21/1990	1.54E+12	ND <4.6E4	ND <3.1E4	>7.3	ND <5E-6
2	6	8/22/1990	1.54E+12	4.64E+04	<4.2E6	7.5	3.00E-04
2	7	8/26/1990	1.54E+12	ND <3.8E4	ND <2.7E4	>7.4	ND <4.2E-6
2	8	8/27/1990	1.54E+12	ND <5.4E4	NA	NA	NA
2	9	8/28/1990	1.54E+12	ND <4.5E4	ND <2.3E4	>7.4	ND <4.5E-6
3	1	3/5/1991		<1.0E8			
3	2	3/5/1991		<8.4E8			
3		Total	1.71E+12	<9.4E8	ND <4.6E6	>3.2	<5.5E-2
3	3	3/7/1991		1.10E+05			
3	4	3/7/1991			ND <1.2E5		
3		Total	1.71E+12	1.10E+05	(0.6 to 7.7)E7	5.3	4.60E-04
3	5	3/9/1991			ND <1.0E5		
3	6	3/9/1991			ND <1.52E5		
		Total	1.58E+12	ND <2.5E5	<2.8E10	>1.8	<1.8
4	1	5/30/1990	2.80E+12	ND <5.2E4	3.00E+09	3	0.11
4	2	5/31/1990	2.80E+12	ND <6.4E4	>1.6E9	<3.2	>5.8E-2
4	3	6/1/1990	2.80E+12	ND <3.7E4	ND <3.4E4	>7.6	<2.6E-6
4	4	6/2/1990	2.80E+12	ND <5.5E4	<1.2E9	>3.4	<4.2E-2
4	5	6/4/1990	2.80E+12	ND <5.7E4	>1.7E9	<3.2	>6.1E-2
4	6	6/5/1990	2.80E+12	ND <6.4E4	>1.3E9	<3.3	>4.7E-2
4	7	6/6/1990	5.60E+12	ND <6.5E4	<2.2E9	>3.4	<7.9E-2
4	8	6/7/1990	2.80E+12	ND <5.5E4	<1.3E9	>3.3	<4.7E-2
4	9	6/8/1990	2.80E+12	ND <6.7E5	ND	>6.6	<2.6E-5
data are presented as presented in test report, although some of the test runs listed do not match with correct date, as listed in the process description; Run 7 has double the spores since run 5 was repeated							
5	MB3	5/5 to 5/8/90	NA	ND 0.36	NA	~ 8	not determined
5	MB1	5/23 - 5/31	NA	ND 0.33	NA	~ 8	not determined
5	EB1	5/17- 5/21	NA	ND 0.31	NA	~ 8	not determined
Emissions results listed above are based on the average of 3 test runs since no spores were detected.							
Spores were charged via bags at a rate of 718 billion/hr.							
Numbers of spores emitted are per hour.based on detection limits of 1 spore per sample. No ash samples were taken.							
6	1	6/23/1990	8.50E+11	5.30E+04	not determined	7.20E+00	not determined
6	4	6/26/1990	8.50E+11	ND 9.0 E3	not determined	> 8	not determined
6	5	6/28/1990	8.50E+11	ND 2.7 E4	not determined	> 7.5	not determined
Number spores charged and spores emitted are reported on a per hour basis not for whole test.							
7	1	11/18/1991	1.40E+12	0*	0	not determ.	not determined
7	2	11/19/1991	1.40E+12	0*	0	not determ.	not determined
7	3	11/20/1991	1.40E+12	0*	0	not determ.	not determined
* Result as reported in test report.. No detection limit was presented in test report							
Overall notes							
Number of spores spiked is the total number spiked during the test run; spores were spiked typically 3-4 times per test							
log reduction = log (spiked spores) - log (spores from emissions + spores from ash). NA = not available, not obtained							
Number of spores exiting stack= spores/dscm · stack flow rate · total sampling time.							
Numbers indicated as "ND <" are for samples where no spores were detected but calculated based on the detection limit.							
Numbers indicated as "<" are for samples where spores were detected, but determined to be less than a certain value							
Numbers of spores indicated as ">" are samples w/ spores too numerous to count, and assigned a value of 200 spores/filter							

Table IV Summary of Microorganism Survivability Pipe Test Results

Facility	Number pipes charged	Number pipes recovered	Number of pipes with no detectable spores	Number pipes with detectable spores (range of spores detected)	Number pipes with spores TNTC
1	54	54	26	25 (1-166)	3
2	27	25	11	12 (1-53)	2
3	27	27	21	6 (1-8)	0
4	27	27	23	1 (1)	3
5	9	9	5	4 (3-15)	0
6	8	8	5	0	3
7	27	13	13	0	0

TNTC = number of colonies were too numerous to count due to insufficient dilution

STATISTICAL ANALYSIS

Data from the six facilities were combined into a single dataset reflecting the log reduction of spores, the total number of spores, primary and secondary combustion chamber temperatures, gas-phase residence time, and stack oxygen (O_2) levels. This combined dataset is shown in Table V.

Table V Data Used in Statistical Analysis

Facility	Run	Log Reduction	# Spores Exiting Stack	Primary Chamber T (°C)	Secondary Chamber T (°C)	Secondary Res. Time (s)	Stack O_2 (%)
1	1	6.8	3.80E+04	770	807	0.12	15.8
1	2	6.0	4.40E+04	758	946	0.11	15.7
1	3	5.7	1.38E+07	815	815	0.13	16.1
1	4	5.9	4.31E+04	846	858	0.11	15.2
1	5	5.6	1.35E+07	784	805	0.12	15.6
1	6	6.5	1.85E+06	772	794	0.12	15.7
1	8	5.6	1.55E+07	792	922	0.11	15.6
1	9	5.9	6.94E+06	785	828	0.11	15.3
1	10	8.2	3.22E+04	785	801	0.12	15.7
2	1	4.5	2.57E+04	1029	1104	0.92	8.5
2	2	7.1	1.28E+05	1087	1142	1.05	7.2
2	3	7.3	5.20E+04	1014	1115	0.98	9.4
2	4	7.2	1.05E+05	863	1070	0.79	7.7
2	5	7.3	4.60E+04	877	1001	0.81	9.2
2	6	7.5	4.64E+04	854	987	0.83	9.8
2	7	7.4	3.80E+04	912	892	1.05	11.8
2	8	-	5.40E+04	892	909	1.10	9.3
2	9	7.4	4.50E+04	904	913	1.14	9.0
3	1	3.2	9.40E+08	345	997	1.49	8.8
3	2	5.3	1.10E+05	316	992	1.79	9.9
3	3	1.8	2.50E+05	338	1016	1.97	9.9
4	1	3.0	5.20E+04	973	964	0.32	10.9
4	2	3.2	6.40E+04	1049	999	0.31	10.1
4	3	7.6	3.70E+04	964	973	0.30	14.3
4	4	3.4	5.50E+04	983	966	0.33	14.1
4	5	3.2	5.70E+04	985	973	0.32	13.9
4	6	3.3	6.40E+04	853	904	0.36	12.0
4	7	3.4	6.50E+04	1005	916	0.36	12.9
4	8	3.3	5.50E+04	1010	894	0.35	14.6
4	9	6.6	6.70E+05	993	903	0.36	13.1
6	1	7.2	5.30E+04	941	1116	-	-
6	4	8.0	9.00E+03	996	1129	-	-
6	5	7.5	2.70E+04	906	1144	-	-

The data were imported into the SAS JMP software and a stepwise regression was performed to examine whether either the variability of the log reduction or the number of spores exiting the stack could be accounted for by either the temperatures, residence time, or oxygen concentrations, both singly and as

cross products. A statistically significant relationship was found where the log reduction could be accounted for with an R^2=0.51 with a 2 parameter model using the primary chamber temperature, the residence time, and their cross product.

Figure 1 shows the resultant leverage plots from the JMP model fit. The leverage plots illustrate the effect of a single parameter while holding all other parameters constant. If the 95% confidence intervals (the dotted lines) cross the horizontal line then the parameter is a statistically significant predictor. The slope of the leverage line shows the effect that parameter imposes on the predicted variable. From Figure 1, it shows that when taken alone, residence time (RT, in seconds) shows a positive correlation with log reduction, which is consistent with the hypothesis that increased residence times would result in better spore destruction. The primary chamber temperature (PRIMARY_T, °C), when examined alone, has a slightly negative correlation with log reduction, which is counter-intuitive since it would be expected that higher temperatures promote better spore destruction. This seeming inconsistency, however, is resolved when examining the leverage plot of the cross product of temperature and residence times (PRIMARY_T · RT), which shows a positive correlation with spore destruction. The cross product term also showed much narrower 95% confidence interval bands and a much lower "P-value", suggesting that it is a more significant predictor of spore destruction. A P-value less than 0.05 indicates a statistically significant predictor. This suggests that the facilities with the longer secondary combustion chamber residence times and a higher primary combustion chamber temperature yielded the highest degree of spore destruction. It must be noted however, that the data showed a significant amount of variability in QA that was achieved, and that many measurements were driven by detection limits.

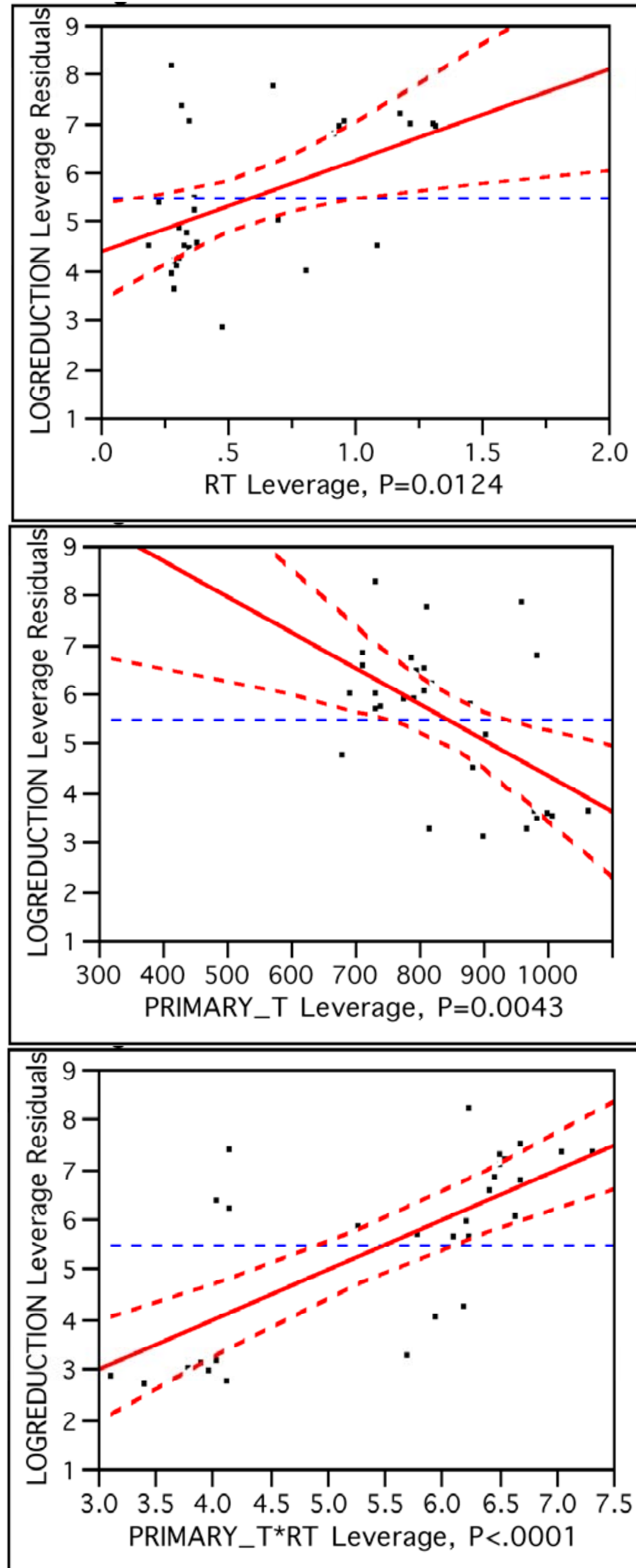

Fig. 1 Leverage Plots from Statistical Analysis
(R^2=0.51; overall P Value=0.0004)

CONCLUSIONS

Microorganisms were spiked with the medical waste feed and for the majority of the test runs at the MWIs tested by EPA, at least a five log reduction in spores was achieved. However, viable spores were detected in the flue gas at the outlet of the secondary combustion chamber and in the incinerator residue for several test runs. That some spores were not destroyed may be due to technical limitations of the MWIs, or to artifacts of the test procedures. There are several potential sources of bias in the data (i.e., the number of spores emitted), including high bias and false positives due to field contamination (as indicated by some of the false positives detected in the field blanks) and low bias due to a high detection limit.

The data presented here may not be totally representative of an actual scenario in which building materials potentially contaminated with B. Anthracis spores are incinerated in an MWI. The tests were conducted over 10 years ago on relatively small hospital MWIs with types of combustion and air pollution control equipment and designs that may not be in use today. For example, due to the cost of complying with air emission standards and guidance developed in the 1990s, medical waste disposal has shifted from small hospital MWIs to larger commercial MWIs with state-of-the-art incinerator and air pollution control technology. Further, these tests were worst-case scenarios with billions of spores charged to the MWIs; in an actual disposal scenario, we would expect that very few target microorganisms would be viable in the waste from a decontaminated building. (The exception to this is when potentially bio-contaminated interior building materials are removed without first being fumigated). These data may also be considered somewhat non-representative since these tests used the heat resistant B. Stearothermophilus bacterium and sampling occurred prior to the air pollution control device. (It is hypothesized that an air pollution control system would further contribute to the overall destruction of viable spores in the flue gas stream).

Nevertheless, due to the real possibility that bacterial spores may escape destruction in a MWI, it may be prudent to carefully select facilities so as to minimize potential escape of microorganisms into the environment. Further research and development are needed to minimize analytical biases and lower the detection limit for the tests methods used to measure viable microorganisms in incinerator exhaust gases and ash.

ACKNOWLEDGEMENTS

We would like to acknowledge the personnel from EPA's Office of Air Quality Planning and Standards and EPA's Office of Solid Waste who were involved with the MWI emissions testing and subsequent development of the test reports referenced in this document.

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