LA-SUB-00-82

Technology Maturation

of

Dispersion Technology to Augment BioRemediation

Final Report

54GO Performance Chemicals
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from

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DISCLAIMER

LANL PROJECT#04394-001-99-35
"Dispersion Technology to Augment Bio-Remediation"

Objective: "Dispersion Technology to Augment Bio-Remediation" was to develop and implement protocols for bench sized field-testing and laboratory analysis to further evaluate and support the use of dispersion products such as 54GO to augment bio-remediation with selected microbes. Microbes alone have been utilized for years to remediate contaminated areas. However, in many cases microbes alone have taken several years to achieve acceptable remediation levels. Preliminary tests, performed by 54GO Performance Chemicals, have shown that when microbes are used in conjunction with a dispersant such as 54GO, the time for acceptable remediation is shortened. In this project four waste types are to be tested using 54GO in concert with stress selected microbes. These four waste types are 1] creosote/PAH (polycyclic aromatic hydrocarbons) contaminated soil, 2] manufactured gas plant waste, 3] soil saturated with crude oil and 4] soil saturated with diesel fuel. These wastes were selected because they represent known areas of concern in Northern New Mexico. The analytical objective is to analyze these four waste types using a] microbes alone, b] 54GO alone and c] microbes and 54GO in concert. The success of the testing will be monitored by testing for total petroleum hydrocarbons [TPH] and polycyclic aromatic hydrocarbons [PAH] during the six week test period.

Summary: The data obtained from this preliminary short-term project demonstrated that dispersants such as 54GO are effective in accelerating the bio-remediation of soils containing contamination from waste oils, diesel, creosote and manufactured gas plant waste. This acceleration appears to be in the observation that 54GO quickly separates the hydrocarbon wastes from the soil particles, thereby allowing closer contact with the microbes. The project time limitations impacted the scope of data but was able to demonstrate a general reduction in the levels of contaminates. In this project only Total Petroleum Hydrocarbons [TPH] and 17 polycyclic aromatic hydrocarbons [PAH] were analyzed. These were chosen because they are standardized by EPA methodology. The raw data from these analytical methods indicate that there are many more intermediate metabolites from the bio-remediation process that were not identified or measured [a limitation of the 17 analyte EPA Method 8270 protocol]. The limited data from these bio-reactors indicates that when both 54GO [dispersant] and stress selected microbes are used the reduction of contaminate metabolites is the greatest. The use of microbes alone was also effective, but not consistent and to a lesser degree. An additional observation with 54GO, either alone or with microbes is that significant amounts of hydrocarbons were "extracted or released" from the test soils and became a separate phase floating on the surface of these bio-reactors. The levels of floating "oil" in these bio-reactors made mixing and sampling difficult tasks. This latter effect of, 54GO, indicates that this family of dispersants are excellent candidates for classic soil washing techniques and may be better served by pre-treating waste soils before mixing with microbes. It is estimated that 75% or more of the hydrocarbons were in the "oil" phase in these bio-reactors even in low water conditions [saturated soil].

Objectives summary:

1] Selection of test samples was met through the following four waste types, all found in Northern New Mexico:

a] a sandy loam soil from an abandoned refinery; containing both heavy crude oils and burnt oils from a flare pit.

b] a heavy clay soil containing #2 diesel in high levels [spill conditions]

c] a sandy loam soil from a manufactured gas plant, which contains asphalt like heavy hydrocarbons that are high in PAH contaminates.

d] a loamy sand from a railroad area that is contaminated with creosote and creosote wastes, which are high in PAH contaminates.

2] Protocols for the operation of the 12 bio-reactors, developed for arid and hot conditions were researched and written. These protocols were then used in this project. In future tests the protocol will be modified due to the observation that the dispersant 54GO produced a third phase of floating "oils" that were difficult to deal with when adding make-up water, mixing and sampling the bio-reactors. These protocols may be modified, in the future, to include a pre-washing of the contaminated soils with 54GO and higher levels of water to first remove the third oily phase before the bio-remediation test phase begins. If this type of pre-washing were performed here the absolute levels of contaminates would have been reduced significantly before the introduction of microbes to begin the bio-remediation process. Visual observation suggests that at least 75% of the hydrocarbons were "dispersed" into the oily layer by 54GO within the first few hours of the test protocol.

3] Sampling and analysis of the bio-reactors was accomplished in accordance with the protocol at 0, 2, 4 & 6 week intervals. Prior to each sampling the bio-reactors were mixed an extra cycle, in addition to the daily mixing to adjust the water content. Even with this extra mixing there were free liquid hydrocarbons in the 54GO treated samples. This sampling difficulty produced some abnormalities in the raw data, such as the final test for TPH in one sample showing a higher level of TPH that was in the original sample. Even with these difficulties the overall analytical evaluation of the bio-reactors appears to be successful. The data shown in the data appendix demonstrates that there appears to be a shift downward in the high molecular mass of PAH contaminates to lower mass PAH contaminates. This downward shift is also seen in somewhat elevated amount of the lower mass PAH contaminates. Both of these observations are expected with bio-remediation using microbes [biochemical in nature]. In the scheme of the biochemical breakdown of complex and large molecules the appearance of smaller and smaller units is expected. If this general biochemical principle is followed by these specific strains of stress selected microbes then the breakdown pathways would in general be as follows:

benzopyrenes - - > benzofluoranthenes - - > pyrenes/chrysenes - - > acenaphthenes/fluorenes - - > anthracenes/napthalenes - - > BTEX types - - > mixed alcohols/aldehydes/acids - - > carbon dioxide/water ...

When the analytical data is examined this general type of contaminate reduction is seen in the MGP and Creosote wastes and to a lesser degree by the oil and diesel wastes. Even in the oil and diesel wastes, which contain small amounts of the lower mass contaminates, this reduction is seen. It is unlikely that a single strain of microbe is accomplishing this reduction but a family of interrelated strains that work in concert/synergism. Aerobic Microbe Counts were performed by Gas Analysis Services, of Farmington, NM. This data is also found in the data appendix. In general the microbe counts from the oil and diesel show the least consistency, however there is a general increase in the total aerobic microbe count in the MPG and creosote waste reactors.

4] The final objective of this project was to recommend uses of this analytical data. This brief project did yield the following:

a] The ability of 54GO to disperse hydrocarbons from soils suggests that this family of dispersants be further tested as soil washing or soil extraction augmentation chemicals. The data from this project suggests that 75% or more of total hydrocarbons are dispersed into the oily phase, which could be separate by traditional methods before bio-remediation begins. This pretreatment would be a significant augmentation of the overall process.

b] 54GO appears to accelerate the bio-remediation process in most of the waste types tested. This acceleration seems driven by our observation that 54GO removes the waste hydrocarbons from soil particles and/or disperses hardened spheroids of waste hydrocarbons, that are seen in two waste types [MPG and Creosote]. When treated with the 54GO these soil bound hydrocarbons and hydrocarbon containing spheroids are dispersed into the liquid phase of the bio-reactor. The microbes now have a dispersed surface to initiate metabolism [bio-remediation]. The time for the specific microbes to digest of a molecule thick layer of waste from soil particles or spheroids is a very slow process like peeling layers off an onion. The dispersion of these wastes now allows the bio-remediation process to proceed in a significantly shorter time frame. [weeks/months <u>vs</u> years]

c] The use of 54GO dispersants, along with selected microbes appears to be an excellent candidate for <u>in situ</u> bio-remediation. This selection is due to our observations of the reduction, in mass quantities of PAH molecules, across the spectrum of the 17 tested PAH contaminates. A candidate is judged according to its ability to reduce the highest number of specific contaminates; the larger the number the better candidate.

d] The subcontractor is in the process of extending the bio-remediation of the MGP & creosote samples at his own expense, because of the promising data that was obtained from this project]

Summary of Methodology:

1] All samples were treated in bio-reactors made from pre-cleaned 55 gal drums. The samples, representing the four waste streams listed above, were placed in the bio-reactors on a plastic lined and bermed area to contain any possible spills of the waste streams. These four waste streams were subdivided into the twelve (12) variations as listed below. A locked and fenced area at the subcontractor's location was chosen for the test site.

2] All samples were mixed with water and additives to achieve a saturated paste [about a 1:2 sample to water] consistency. Each day samples were stirring and additional water added to maintain the paste's consistency. Samples of each material was collected as described below.

3] Laboratory analysis for TPH-D and EPA 8270 analytes were conducted on the untreated sample materials at the end of the second, fourth and sixth weeks respectively. Microbe estimations counts were established at the beginning, the first, second, fourth and sixth week.

4] Twice daily temperature measurements of the ambient air and bio-reactors were taken in the early morning [average low] and late afternoon [average high].

5] Daily observation and measurement logs were maintained through the six weeks of treatment. All samples were taken in glass bottles cooled on ice and shipped cold to the analytical laboratory [Acculabs Inc., of Durango, CO] under chain of custody protocols. Each morning notes were taken of any noticeable characteristics of the waste streams such as bubbles, molds, colors of liquids, crusts etc.

Waste Streams:

1. Creosote/PAH contaminated soil. The three bio-reactors are coded C-1, C-2 and C-3.
2. Heavy crude asphalt-like material from MGP Plant. The three bio-reactors are coded M-1, M-2 and M-3.
3. Burnt and heavy hydrocarbons in a sandy/loam soil from an abandoned refinery. The three bio-reactors are coded O-1, O-2 and O-3.
4. A clay type soil saturated with Diesel fuel. The three bio-reactors are coded D-1, D-2 and D-3.
5. Each waste stream is subdivided into three separate test systems:
   Sample #1. Material mixed with 54GO.
   Sample #2. Material mixed with 54GO and microbes
   Sample #3. Material mixed with microbes

Technical data reviewed and final summary report written by:
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LANL PROJECT#04394-001-99-35
"Dispersion Technology to Augment Bio-Remediation"

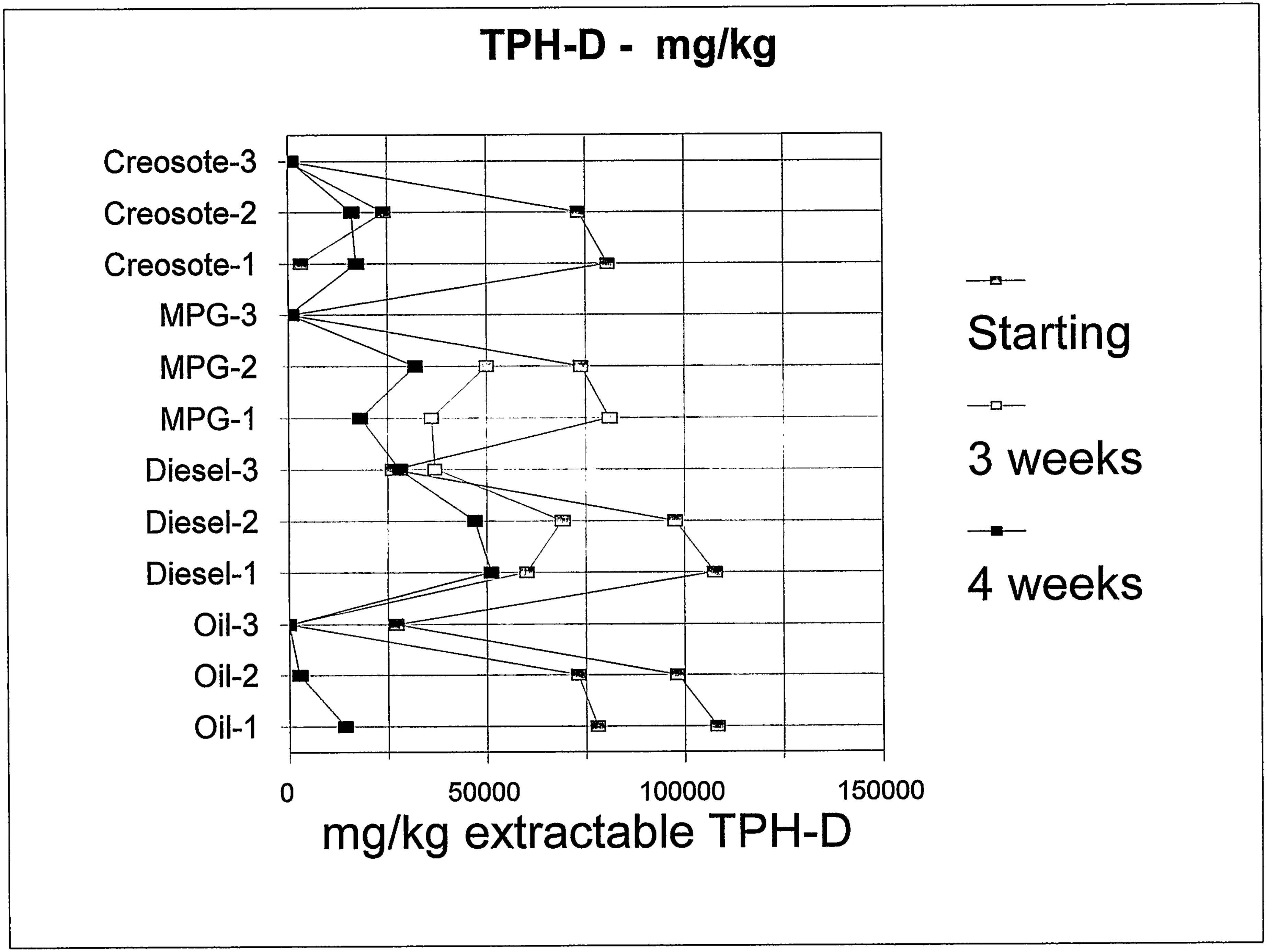
Data Appendix Table of Contents

Bio-reactor sample key and summary

reactor sample code	sample beginning weight kg	volume 54GO added ml	volume microbes added ml	weight kg water added	total apx wt kg in reactor
Oil-1	9.55	3139	0	19.10	31.1
Oil-2	8.86	2910	2910	17.72	31.8
Oil-3	10.68	0	3492	21.36	35.5
Diesel-1	9.55	3139	0	19.10	31.1
Diesel-2	9.89	3247	3247	19.78	35.5
Diesel-3	9.43	0	3400	18.86	31.7
MPG-1	10.91	3583	0	21.82	35.6
MPG-2	13.30	4380	4380	26.60	47.8
MPG-3	12.05	0	3951	24.10	40.1
Creosote-1	8.75	2879	0	17.50	28.6
Creosote-2	8.30	2726	2726	16.60	29.8
Creosote-3	8.75	0	2879	17.50	29.1

TPH-D analysis raw data summary

	sample	total kg	starting	2 weeks	4 weeks	6 weeks
	beginning	weight	TPH-D	TPH-D	TPH-D	TPH-D
Sample	weight kg	in reactor	mg/kg	mg/kg	mg/kg	mg/kg
Oil-1	9.55	31.1	108,212	78,000	14,000	48,000
Oil-2	8.86	31.8	98,197	73,000	2,600	46,000
Oil-3	10.68	35.5	27,052	**	**	18,000
Diesel-1	9.55	31.1	107,599	60,000	51,000	120,000
Diesel-2	9.89	35.5	97,661	69,000	47,000	61,000
Diesel-3	9.43	31.7	26,187	37,000	28,000	200,000
MPG-1	10.91	35.6	81,123	36,000	18,000	21,000
MPG-2	13.30	47.8	73,877	50,000	32,000	34,000
MPG-3	12.05	40.1	571	130	140	100
Creosote-1	8.75	28.6	80,808	3,100	17,000	25,000
Creosote-2	8.30	29.8	73,326	24,000	16,000	19,000
Creosote-3	8.75	29.1	141	0	730	330
** = excessive interference with analysis due to heavy hydrocarbons						

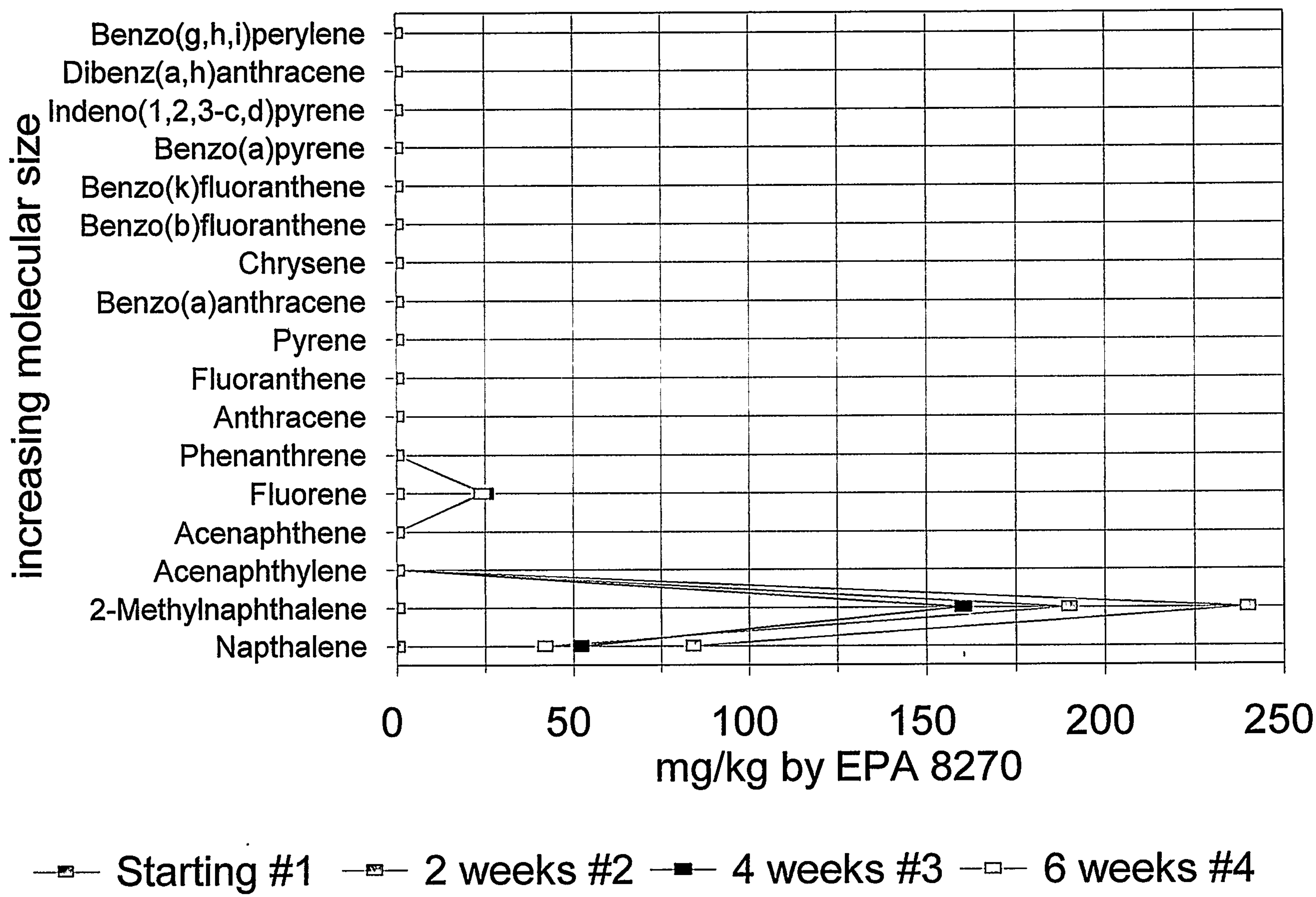


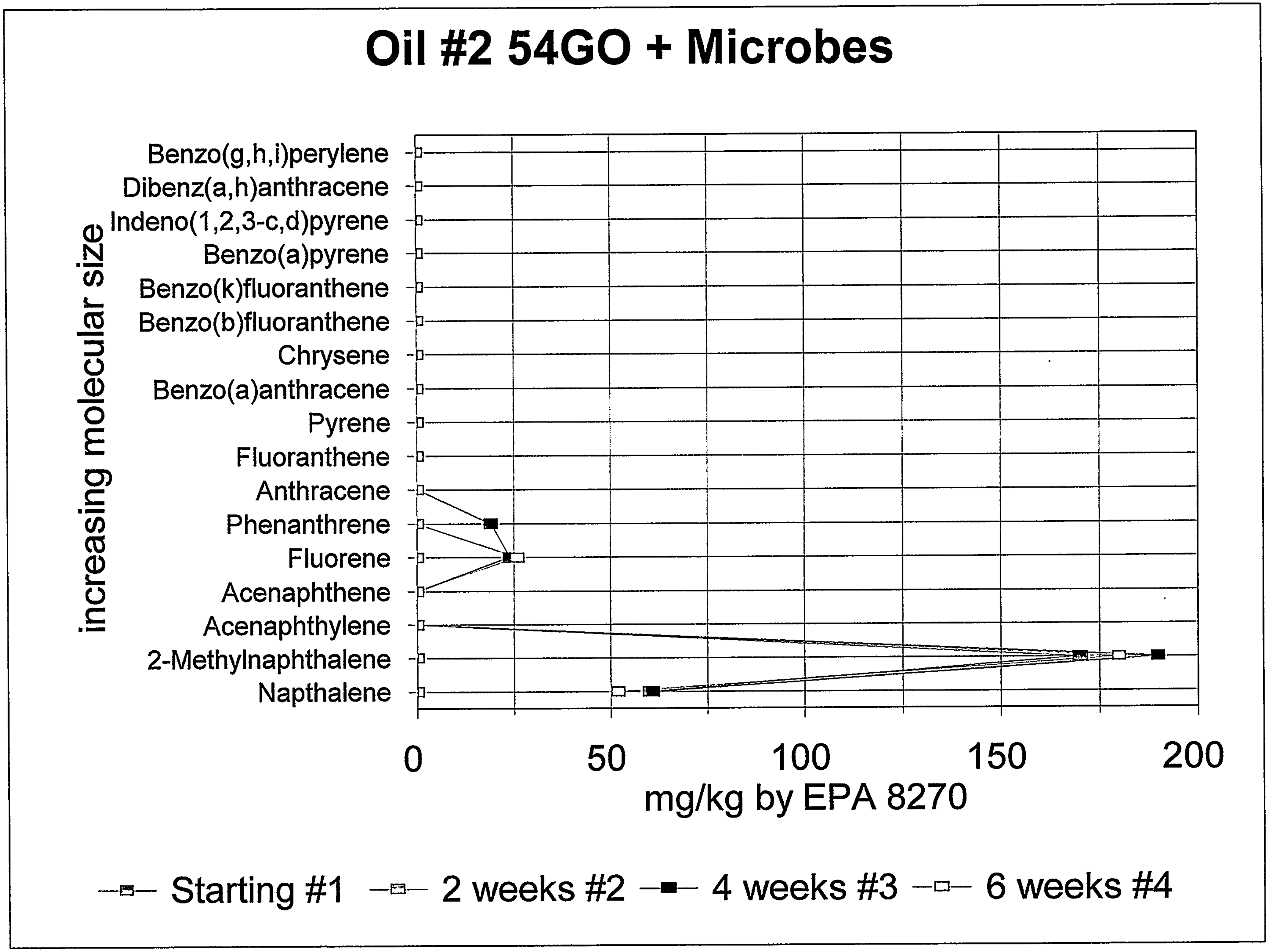
TPH-D - mg/kg
Creosote-3
Creosote-2
Creosote-1
MPG-3
MPG-2
MPG-1
Diesel-3
Diesel-2
Diesel-1
Oil-3
Oil-2
Oil-1
0
50000
100000
150000
mg/kg extractable TPH-D
Starting
3 weeks
4 weeks

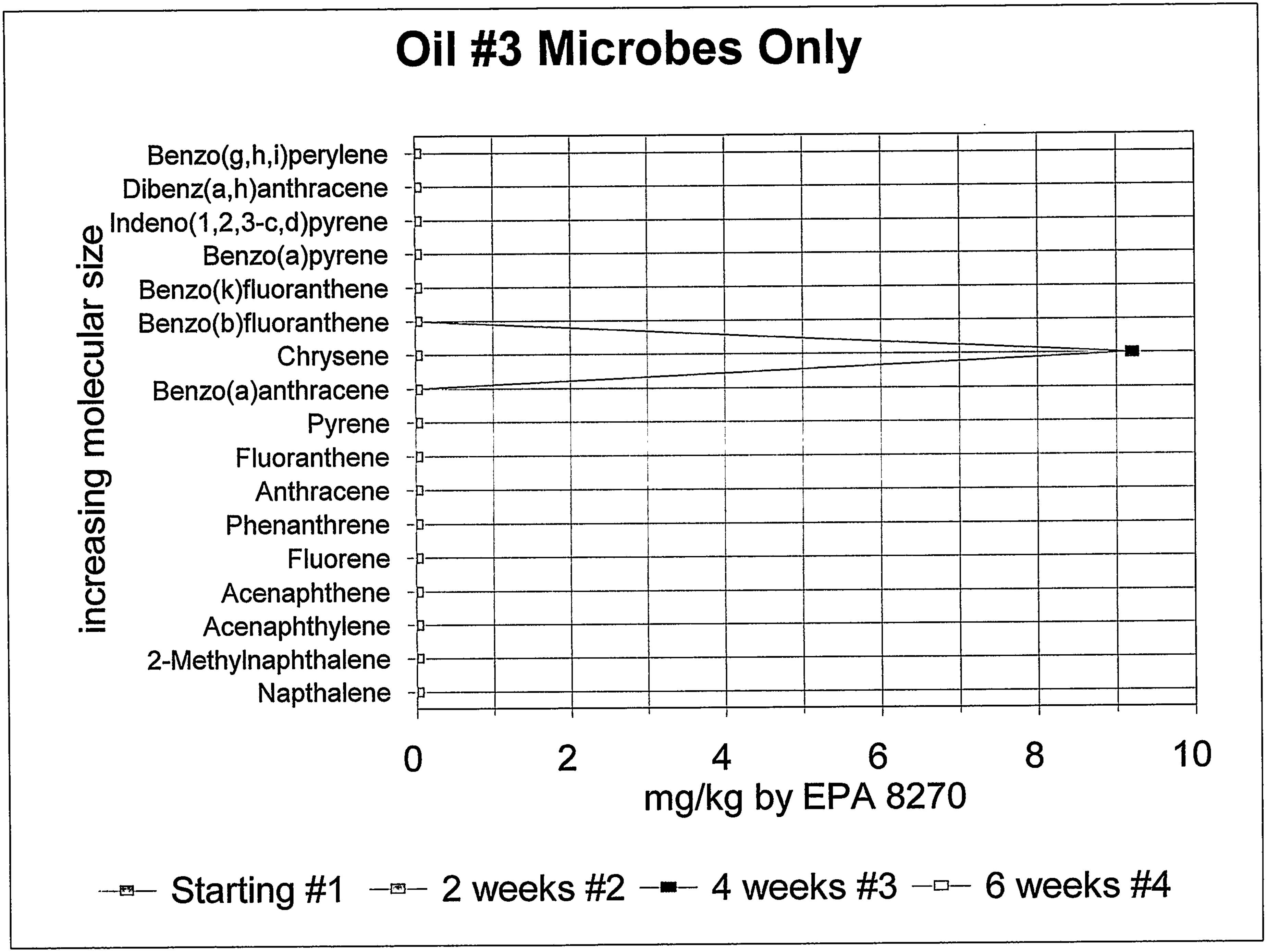
EPA 8270 analysis raw data [mg/kg]

Oil sample O-1	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#2	#4
Napthalene	<17	84	52	42
2-Methylnaphthalene	<17	240	160	190
Acenaphthylene	<17	<34	<17	<20
Acenaphthene	<17	<34	<17	<20
Fluorene	<17	35	25	24
Phenanthrene	<17	<34	<17	<20
Anthracene	<17	<34	<17	<20
Fluoranthene	<17	<34	<17	<20
Pyrene	<17	<34	<17	<20
Benzo(a)anthracene	<17	<34	<17	<20
Chrysene	<17	<34	<17	<20
Benzo(b)fluoranthene	<17	<34	<17	<20
Benzo(k)fluoranthene	<17	<34	<17	<20
Benzo(a)pyrene	<17	<34	<17	<20
Indeno(1,2,3-c,d)pyrene	<17	<34	<17	<20
Dibenz(a,h)anthracene	<17	<34	<17	<20
Benzo(g,h,i)perylene	<17	<34	<17	<20
Oil sample O-2	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#2	#4
Napthalene	<17	60	61	52
2-Methylnaphthalene	<17	170	190	180
Acenaphthylene	<17	<34	<17	<20
Acenaphthene	<17	<34	<17	<20
Fluorene	<17	<34	24	26
Phenanthrene	<17	<34	19	<20
Anthracene	<17	<34	<17	<20
Fluoranthene	<17	<34	<17	<20
Pyrene	<17	<34	<17	<20
Benzo(a)anthracene	<17	<34	<17	<20
Chrysene	<17	<34	<17	<20
Benzo(b)fluoranthene	<17	<34	<17	<20
Benzo(k)fluoranthene	<17	<34	<17	<20
Benzo(a)pyrene	<17	<34	<17	<20
Indeno(1,2,3-c,d)pyrene	<17	<34	<17	<20
Dibenz(a,h)anthracene	<17	<34	<17	<20
Benzo(g,h,i)perylene	<17	<34	<17	<20
Oil sample O-3	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#2	#4
Napthalene	<17	<34	<6.7	<20
2-Methylnaphthalene	<17	<34	<6.7	<20
Acenaphthylene	<17	<34	<6.7	<20
Acenaphthene	<17	<34	<6.7	<20
Fluorene	<17	<34	<6.7	<20
Phenanthrene	<17	<34	<6.7	<20
Anthracene	<17	<34	<6.7	<20
Fluoranthene	<17	<34	<6.7	<20
Pyrene	<17	<34	<6.7	<20
Benzo(a)anthracene	<17	<34	<6.7	<20
Chrysene	<17	<34	9.2	<20
Benzo(b)fluoranthene	<17	<34	<6.7	<20
Benzo(k)fluoranthene	<17	<34	<6.7	<20
Benzo(a)pyrene	<17	<34	<6.7	<20
Indeno(1,2,3-c,d)pyrene	<17	<34	<6.7	<20
Dibenz(a,h)anthracene	<17	<34	<6.7	<20
Benzo(g,h,i)perylene	<17	<34	<6.7	<20

Oil #1 54GO only




Oil #2 54GO + Microbes
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
50
100
150
200
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4

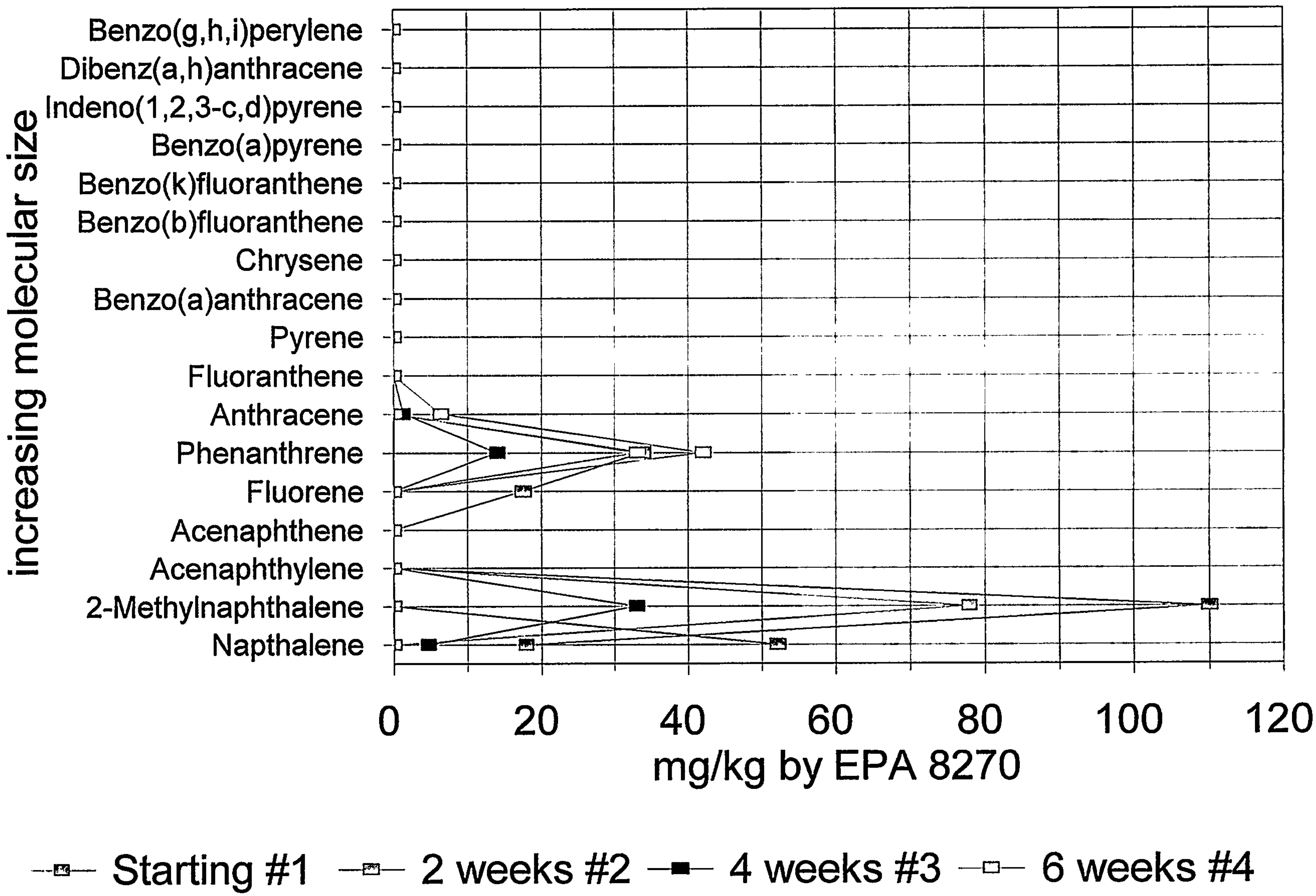


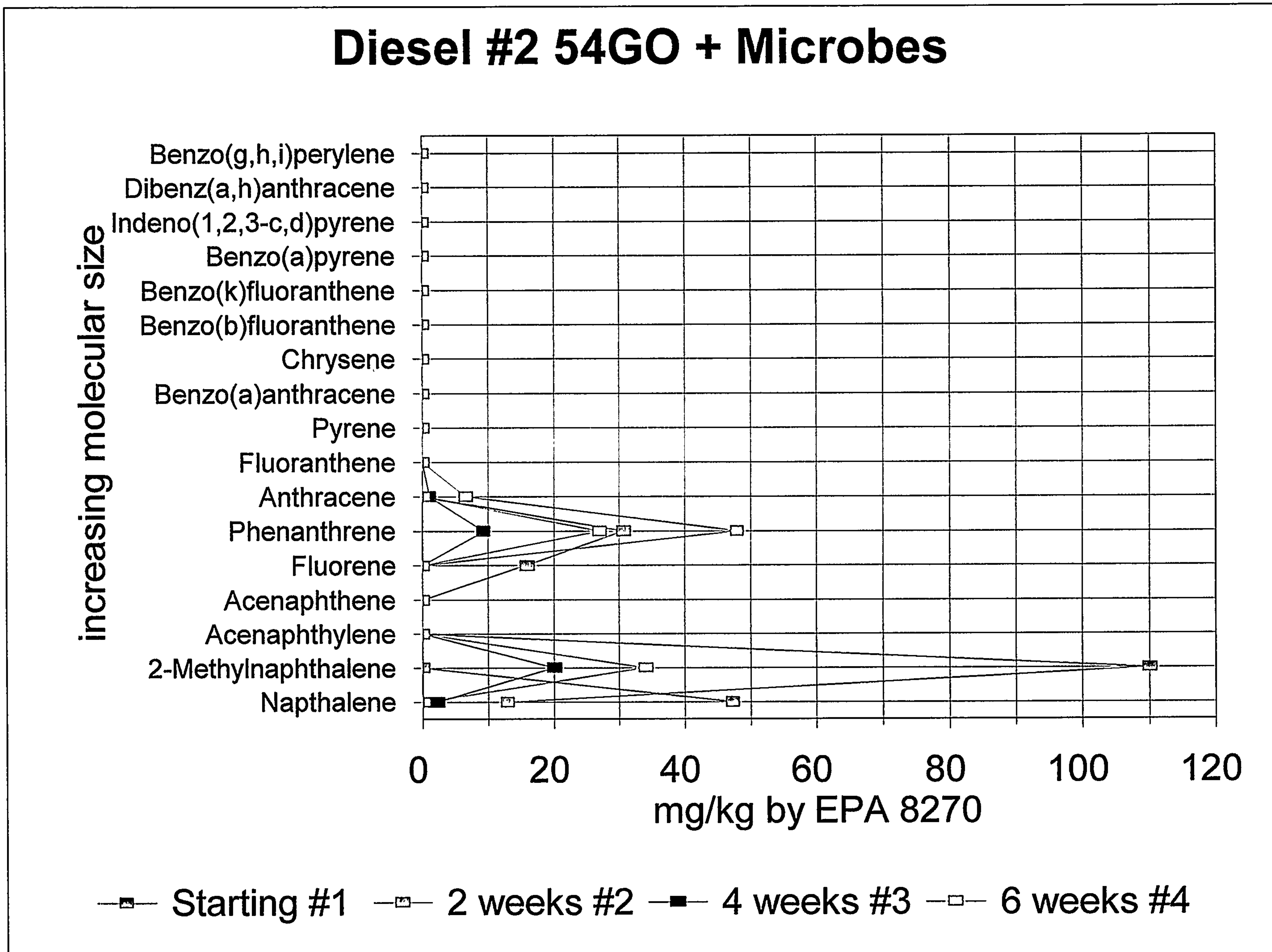
Oil #3 Microbes Only
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
2
4
6
8
10
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4

EPA 8270 analysis raw data [mg/kg]

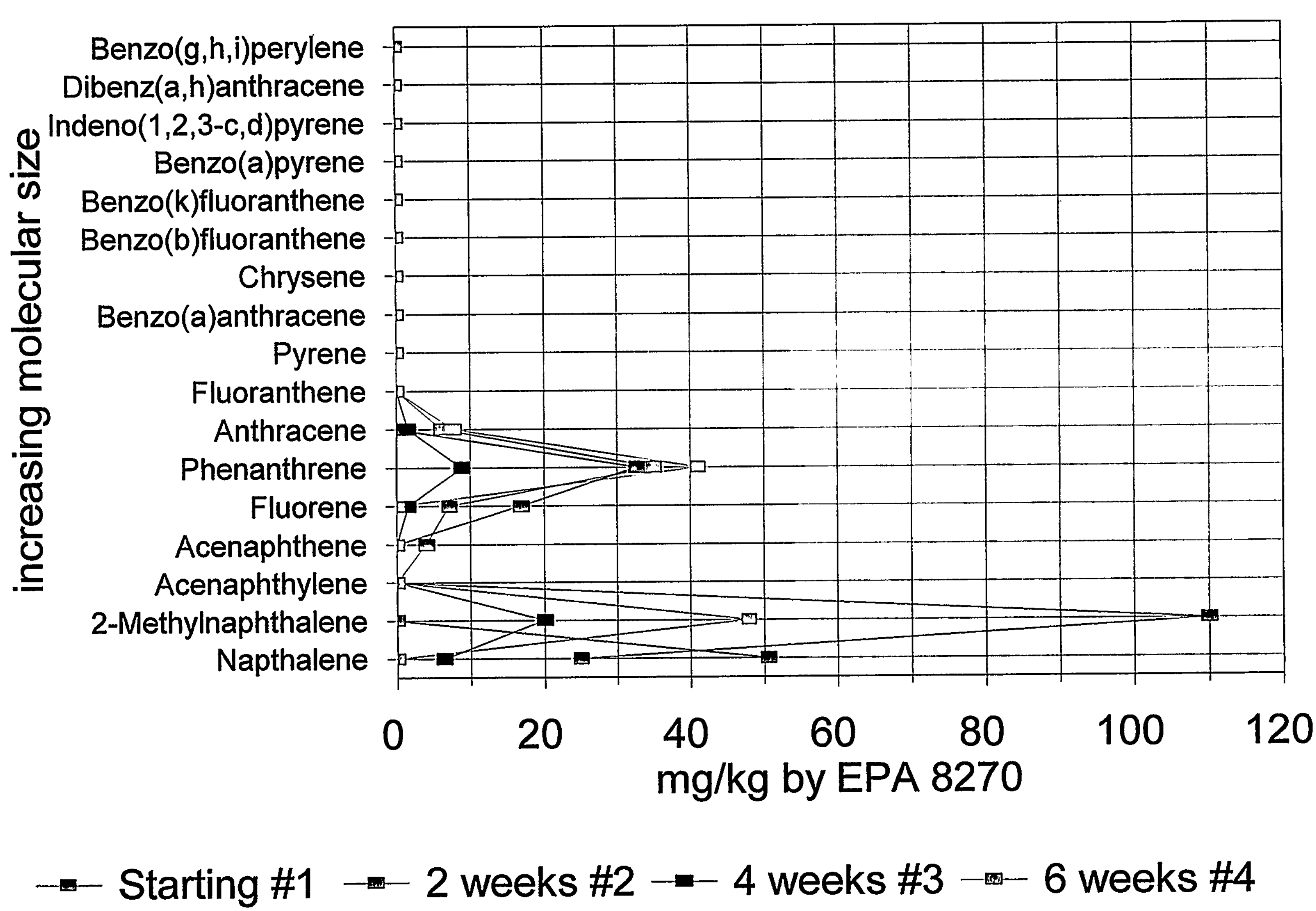
Diesel Sample D-1	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#3	#4
Napthalene	<34	18	4.7	<13
2-Methylnaphthalene	<34	110	33	78
Acenaphthylene	<34	<3.4	<0.67	<13
Acenaphthene	<34	<3.4	<0.67	<13
Fluorene	<34	<3.4	<0.67	<13
Phenanthrene	<34	42	14	33
Anthracene	<34	6.4	1.3	<13
Fluoranthene	<34	<3.4	<0.67	<13
Pyrene	<34	<3.4	<0.67	<13
Benzo(a)anthracene	<34	<3.4	<0.67	<13
Chrysene	<34	<3.4	<0.67	<13
Benzo(b)fluoranthene	<34	<3.4	<0.67	<13
Benzo(k)fluoranthene	<34	<3.4	<0.67	<13
Benzo(a)pyrene	<34	<3.4	<0.67	<13
Indeno(1,2,3-c,d)pyrene	<34	<3.4	<0.67	<13
Dibenz(a,h)anthracene	<34	<3.4	<0.67	<13
Benzo(g,h,i)perylene	<34	<3.4	<0.67	<13
Diesel Sample D-2	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#3	#4
Napthalene	<34	13	2.1	<6.7
2-Methylnaphthalene	<34	110	20	34
Acenaphthylene	<34	<3.4	<0.67	<6.7
Acenaphthene	<34	<3.4	<0.67	<6.7
Fluorene	<34	<3.4	<0.67	<6.7
Phenanthrene	<34	48	9.3	27
Anthracene	<34	6.6	1.1	<6.7
Fluoranthene	<34	<3.4	<0.67	<6.7
Pyrene	<34	<3.4	<0.67	<6.7
Benzo(a)anthracene	<34	<3.4	<0.67	<6.7
Chrysene	<34	<3.4	<0.67	<6.7
Benzo(b)fluoranthene	<34	<3.4	<0.67	<6.7
Benzo(k)fluoranthene	<34	<3.4	<0.67	<6.7
Benzo(a)pyrene	<34	<3.4	<0.67	<6.7
Indeno(1,2,3-c,d)pyrene	<34	<3.4	<0.67	<6.7
Dibenz(a,h)anthracene	<34	<3.4	<0.67	<6.7
Benzo(g,h,i)perylene	<34	<3.4	<0.67	<6.7
Diesel Sample #3	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#3	#4
Napthalene	<34	25	6.4	<6.7
2-Methylnaphthalene	<34	110	20	48
Acenaphthylene	<34	<3.4	<0.67	<6.7
Acenaphthene	<34	4	<0.67	<6.7
Fluorene	<34	7.2	1.5	<6.7
Phenanthrene	<34	35	8.8	41
Anthracene	<34	6.1	1.5	7.7
Fluoranthene	<34	<3.4	<0.67	<6.7
Pyrene	<34	<3.4	<0.67	<6.7
Benzo(a)anthracene	<34	<3.4	<0.67	<6.7
Chrysene	<34	<3.4	<0.67	<6.7
Benzo(b)fluoranthene	<34	<3.4	<0.67	<6.7
Benzo(k)fluoranthene	<34	<3.4	<0.67	<6.7
Benzo(a)pyrene	<34	<3.4	<0.67	<6.7
Indeno(1,2,3-c,d)pyrene	<34	<3.4	<0.67	<6.7
Dibenz(a,h)anthracene	<34	<3.4	<0.67	<6.7
Benzo(g,h,i)perylene	<34	<3.4	<0.67	<6.7

Diesel #1 54GO only



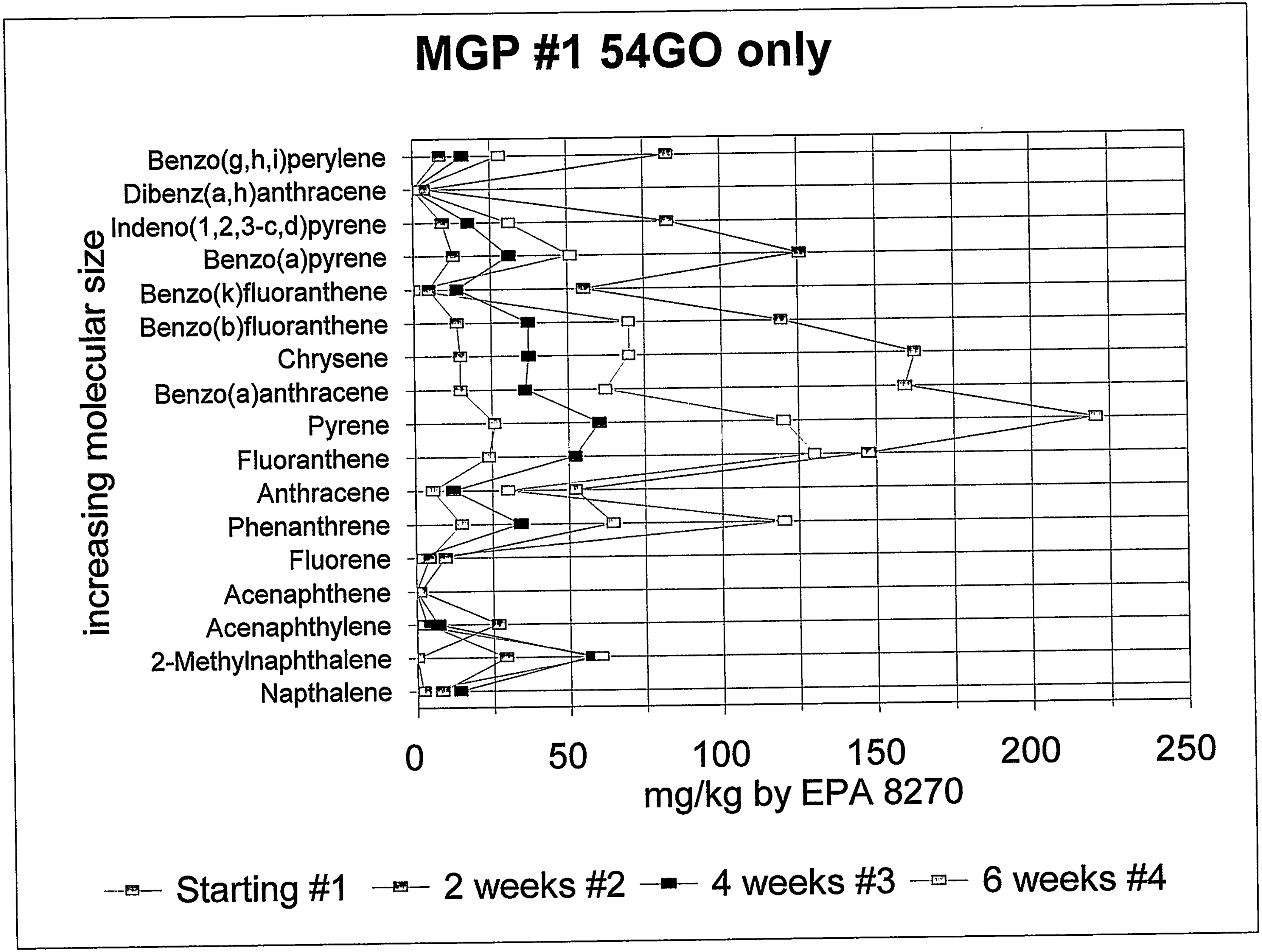

Diesel #2 54GO + Microbes
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
20
40
60
80
100
120
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4

Diesel #3 Microbes only

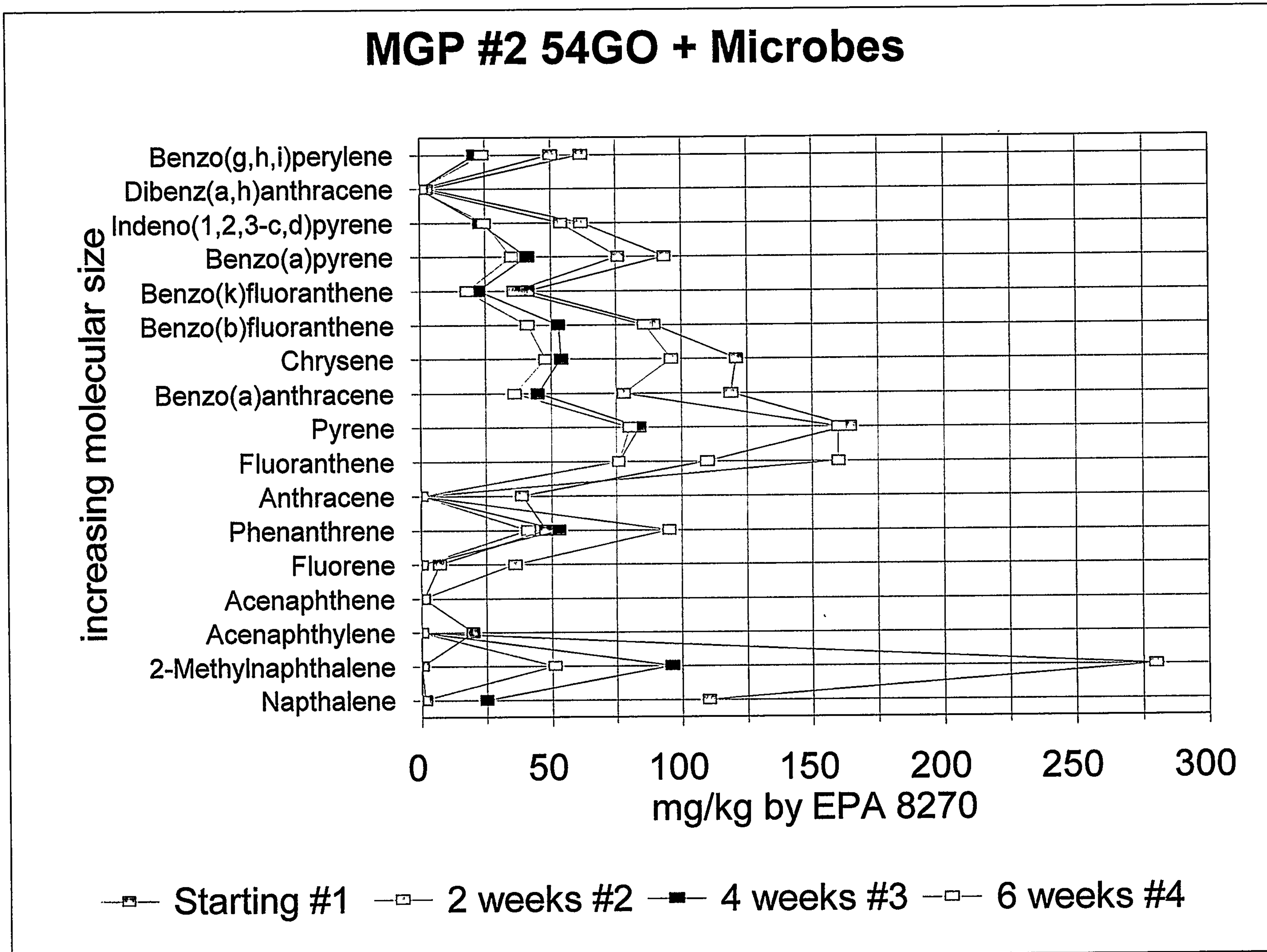


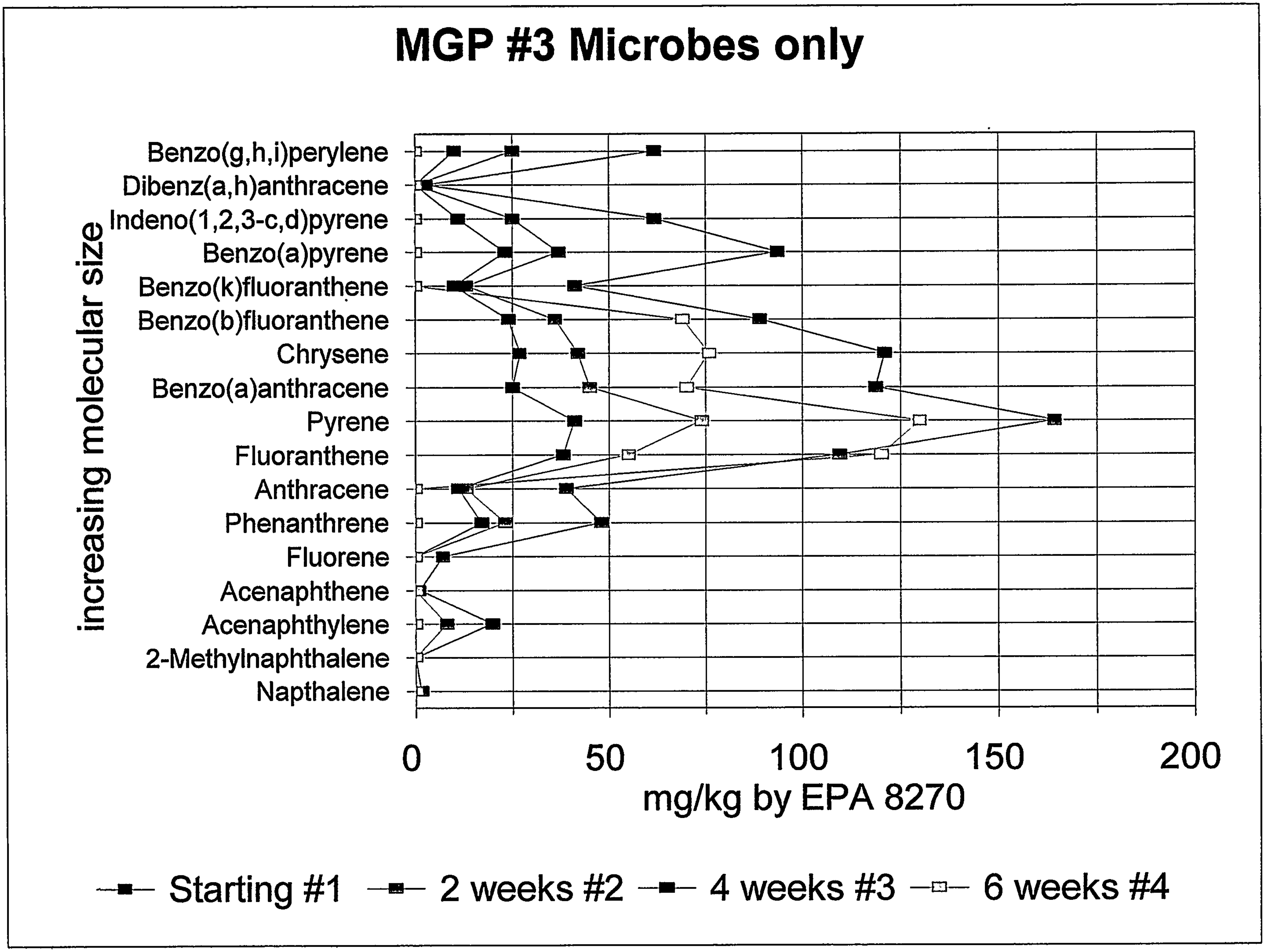
EPA 8270 analysis raw data [mg/kg]

MGP Sample #M-1				
	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#3	#4
Napthalene	2	8.1	14	<27
2-Methylnaphthalene	0	29	57	60
Acenaphthylene	27	3.5	6.9	<27
Acenaphthene	1	<3.4	<6.7	<27
Fluorene	10	4.2	<6.7	<27
Phenanthrene	64	15	34	120
Anthracene	52	5.5	12	30
Fluoranthene	147	24	52	130
Pyrene	221	26	60	120
Benzo(a)anthracene	159	15	36	62
Chrysene	162	15	37	70
Benzo(b)fluoranthene	120	14	37	70
Benzo(k)fluoranthene	55	4.9	14	<27
Benzo(a)pyrene	126	13	31	51
Indeno(1,2,3-c,d)pyrene	83	9.4	18	31
Dibenz(a,h)anthracene	4	<3.4	<6.7	<27
Benzo(g,h,i)perylene	83	8.9	16	28
MGP Sample #M-2	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#3	#4
Napthalene	1	110	25	<13
2-Methylnaphthalene	0	280	96	51
Acenaphthylene	20	<34	<34	<13
Acenaphthene	1	<34	<34	<13
Fluorene	7	36	<34	<13
Phenanthrene	48	95	53	41
Anthracene	39	<34	<34	<13
Fluoranthene	110	160	76	76
Pyrene	164	160	84	80
Benzo(a)anthracene	119	78	45	36
Chrysene	121	96	54	48
Benzo(b)fluoranthene	89	86	53	41
Benzo(k)fluoranthene	41	36	22	18
Benzo(a)pyrene	94	76	41	35
Indeno(1,2,3-c,d)pyrene	62	54	23	25
Dibenz(a,h)anthracene	3	<34	<34	<13
Benzo(g,h,i)perylene	62	50	21	24
MGP Sample #M-3	6/28/99	7/14/99	7/28/99	8/11/99
	#1	#2	#3	#4
Napthalene	2	<6.7	<6.7	<67
2-Methylnaphthalene	0	<6.7	<6.7	<67
Acenaphthylene	24	8.1	<6.7	<67
Acenaphthene	1	<6.7	<6.7	<67
Fluorene	8	<6.7	<6.7	<67
Phenanthrene	57	23	17	<67
Anthracene	46	13	11	<67
Fluoranthene	131	55	38	120
Pyrene	196	74	41	130
Benzo(a)anthracene	141	45	25	70
Chrysene	144	42	27	76
Benzo(b)fluoranthene	106	36	24	69
Benzo(k)fluoranthene	49	13	10	<67
Benzo(a)pyrene	112	37	23	<67
Indeno(1,2,3-c,d)pyrene	73	25	11	<67
Dibenz(a,h)anthracene	3	<6.7	<6.7	<67
Benzo(g,h,i)perylene	73	25	10	<67



MGP #1 54GO only
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
50
100
150
200
250
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4


MGP #2 54GO + Microbes
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
50
100
150
200
250
300
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4



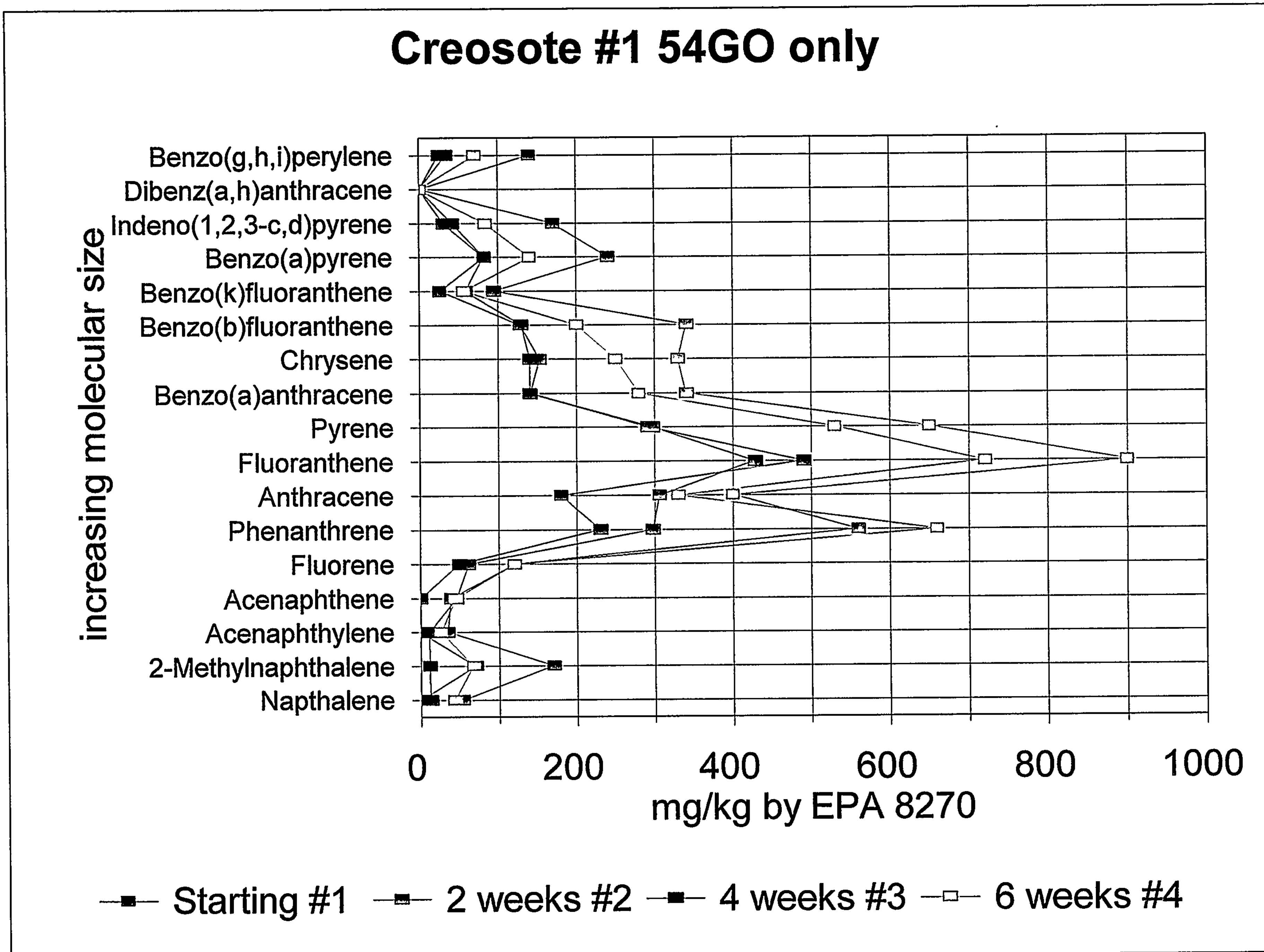
MGP #3 Microbes only
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
50
100
150
200
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4

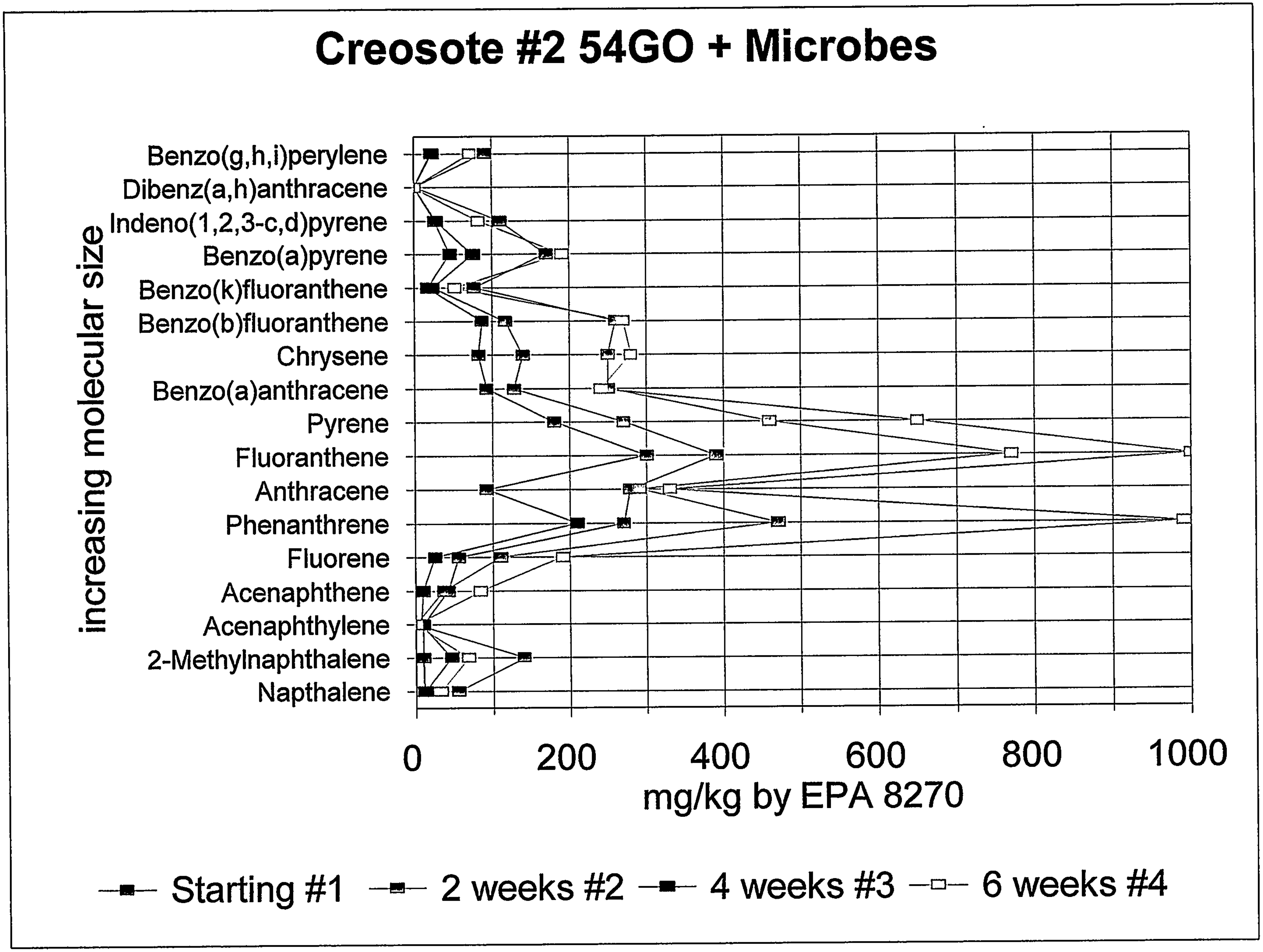
EPA 8270 analysis raw data [mg/kg]

Creosote Sample # C-1	6/28/99	7/14/99	7/28/99	8/11/99
mg/kg	#1	#2	#3	#4
Napthalene	12	53	<17	43
2-Methylnaphthalene	11	170	69	67
Acenaphthylene	10	35	<17	26
Acenaphthene	46	39	<17	44
Fluorene	61	120	49	120
Phenanthrene	297	560	230	660
Anthracene	306	400	180	330
Fluoranthene	428	900	490	720
Pyrene	297	650	290	530
Benzo(a)anthracene	141	340	140	280
Chrysene	153	330	140	250
Benzo(b)fluoranthene	128	340	130	200
Benzo(k)fluoranthene	26	94	58	56
Benzo(a)pyrene	83	240	82	140
Indeno(1,2,3-c,d)pyrene	31	170	42	84
Dibenz(a,h)anthracene	<6.7	<34	<17	<13
Benzo(g,h,i)perylene	25	140	34	70

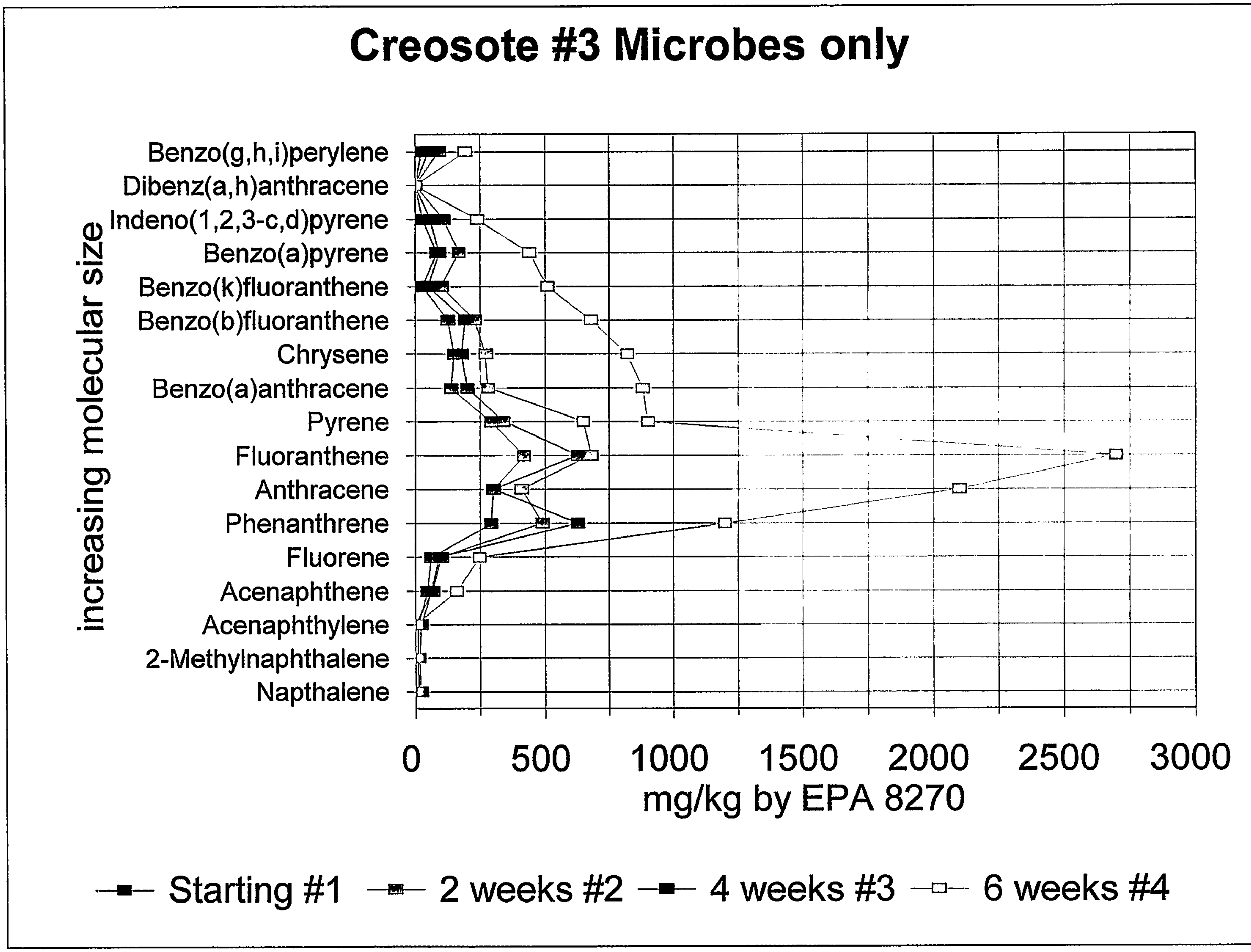
Creosote Sample # C-2	6/28/99	7/14/99	7/28/99	8/11/99
mg/kg	#1	#2	#3	#4
Napthalene	11	55	12	32
2-Methylnaphthalene	10	140	46	68
Acenaphthylene	9	<34	7.3	<27
Acenaphthene	42	36	9.5	84
Fluorene	56	110	25	190
Phenanthrene	270	470	210	990
Anthracene	279	290	92	330
Fluoranthene	390	770	300	1000
Pyrene	270	460	180	650
Benzo(a)anthracene	128	250	93	240
Chrysene	139	250	82	280
Benzo(b)fluoranthene	117	260	87	270
Benzo(k)fluoranthene	24	77	17	52
Benzo(a)pyrene	75	170	46	190
Indeno(1,2,3-c,d)pyrene	28	110	27	82
Dibenz(a,h)anthracene	<6.7	<34	<6.7	<27
Benzo(g,h,i)perylene	23	91	22	72

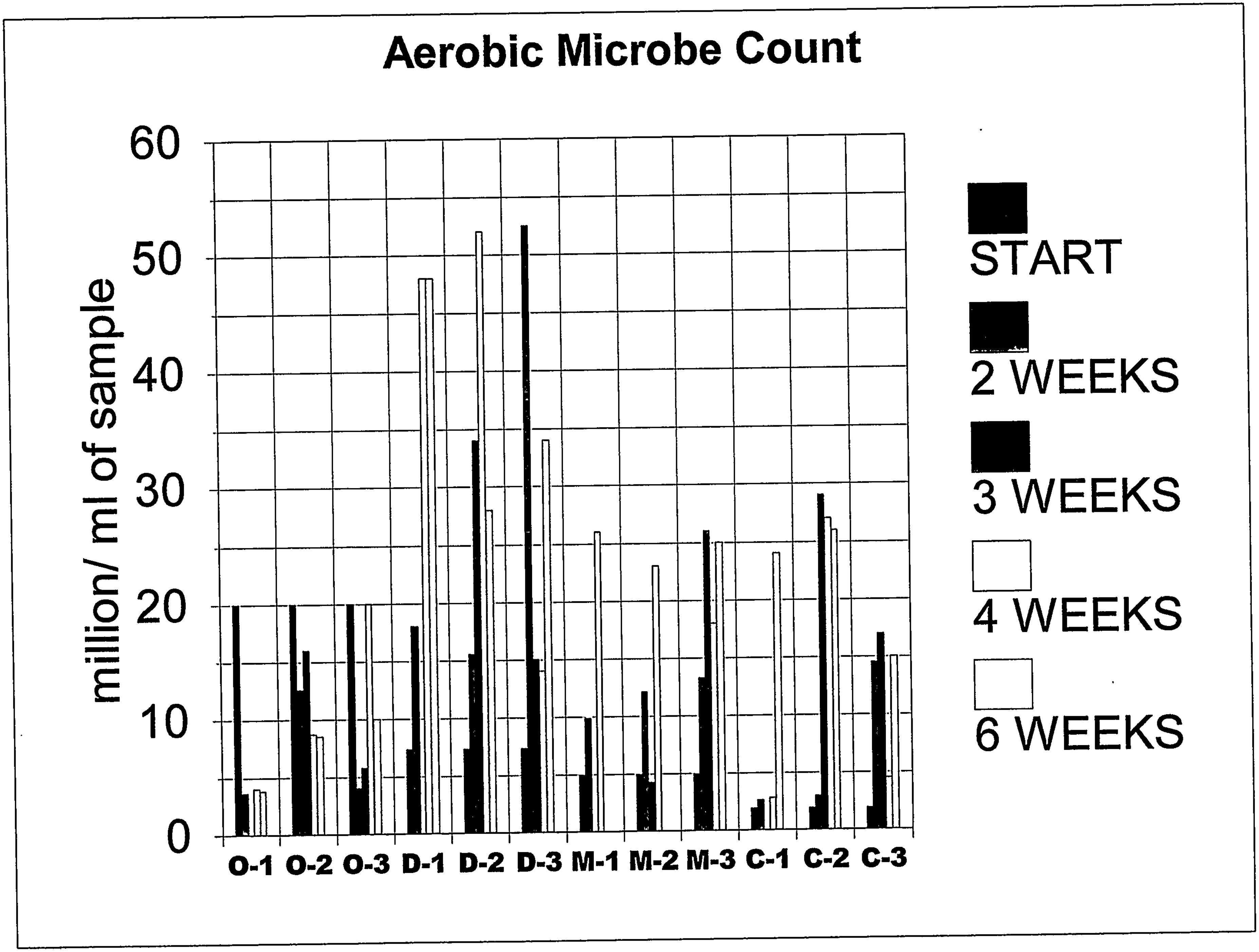
Creosote Sample # C-3	6/28/99	7/14/99	7/28/99	8/11/99
mg/kg	#1	#2	#3	#4
Napthalene	12	<34	19	<67
2-Methylnaphthalene	11	<34	15	<67
Acenaphthylene	10	<34	21	<67
Acenaphthene	45	65	60	160
Fluorene	60	100	92	250
Phenanthrene	292	490	630	1200
Anthracene	301	410	300	2100
Fluoranthene	421	680	630	2700
Pyrene	292	650	340	900
Benzo(a)anthracene	138	280	200	880
Chrysene	150	270	180	820
Benzo(b)fluoranthene	126	230	190	680
Benzo(k)fluoranthene	26	100	49	510
Benzo(a)pyrene	81	170	92	440
Indeno(1,2,3-c,d)pyrene	30	110	57	240
Dibenz(a,h)anthracene	<6.7	<34	<6.7	<67
Benzo(g,h,i)perylene	25	91	49	190


Creosote #1 54GO only
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
increasing molecular size
0
200
400
600
800
1000
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4



Creosote #2 54GO + Microbes
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
200
400
600
800
1000
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4


Creosote #3 Microbes only
increasing molecular size
Benzo(g,h,i)perylene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(a)pyrene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Chrysene
Benzo(a)anthracene
Pyrene
Fluoranthene
Anthracene
Phenanthrene
Fluorene
Acenaphthene
Acenaphthylene
2-Methylnaphthalene
Napthalene
0
500
1000
1500
2000
2500
3000
mg/kg by EPA 8270
Starting #1
2 weeks #2
4 weeks #3
6 weeks #4



Aerobic Microbe Count
million/ ml of sample
0
10
20
30
40
50
60
O-1
O-2
O-3
D-1
D-2
D-3
M-1
M-2
M-3
C-1
C-2
C-3
START
2 WEEKS
3 WEEKS
4 WEEKS
6 WEEKS