A History of Beryllium Exposure Assessment

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Published Exposure Assessments

- 1940s
  - Acute disease is associated with occupational exposures over 100 µg/m^3
  - CBD is associated with ambient air levels over 0.01 µg/m^3
- 1950s - Exposure monitoring and control programs instituted
- 1970s – Personal versus DWA monitoring
- 1990s – CBD cases associated with exposures below 2 µg/m^3 OSHA PEL
- 2000s – Investigations of risk determinants

Non-Occupational CBD
Eisenbud et al. 1949

- 11 cases of CBD among neighbors of a Be production plant, 5 of 500 within ¼ mile of the plant.
- Aerosols were primarily BeO fume from rooftop air cleaners exhausting CuBe alloying operations
- Conclusion: Mean level at ¾ miles from the plant was between 0.01 and 0.1 $\mu g/m^3$

Estimates Arrived at Graphically

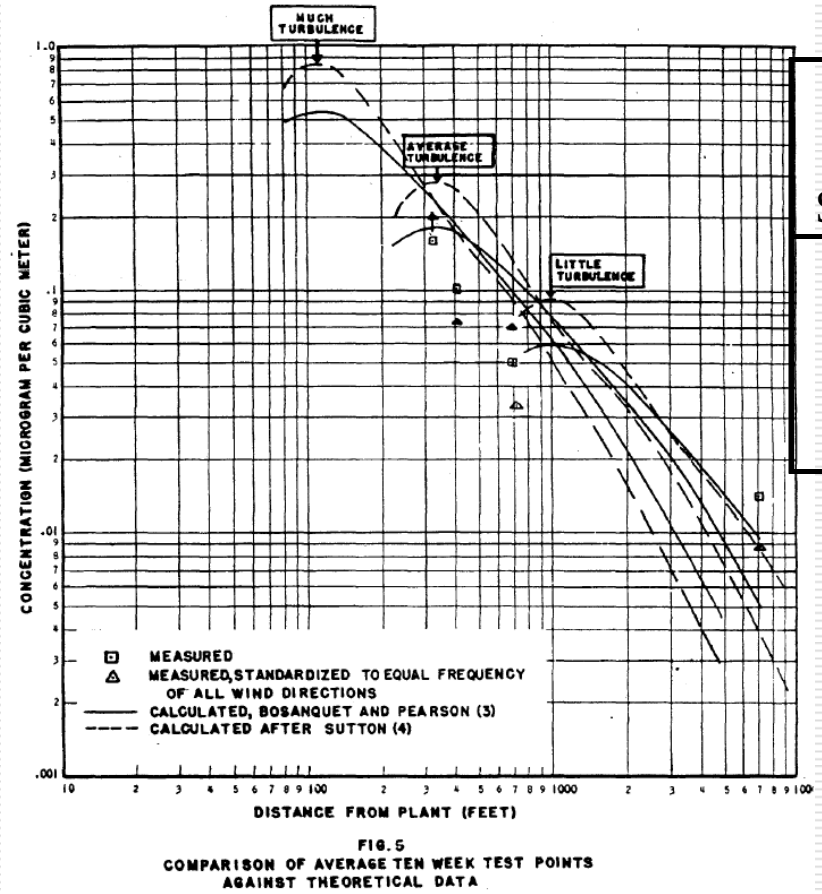


FIG. 5
COMPARISON OF AVERAGE TEN WEEK TEST POINTS AGAINST THEORETICAL DATA

Table 3

Station	Feet from Plant	Average Concentration	Range
1	350	0.15	0.000 - 2.1
2	750	0.05	0.000 - 0.28
3	420	0.1	0.000 - 1.1
4	650	0.05	0.000 - 0.46

- A 5th station at 7000 ft was added later and operated for 3 weeks instead of 10
- Mean: 0.014 µg/m^3
- Range: 0.000 – 0.250

Non-Occupational CBD
Eisenbud and Lisson 1983

- 30-year follow-up based on Beryllium Case Registry
- 17 additional occupational cases among former workers were diagnosed by community physicians
- 1 additional non-occupational case also within ¾ mile of the plant

Health Protection in Be Facilities

Breslin and Harris – 1958 (HASL-36)

- Summarizes 10 years of Health and Safety Laboratory inspections for compliance with AEC standards
- AEC exposure standard – 2 µg/m^3 daily weighted average (DWA) on a quarterly basis.
- DWA combines area samples collected at 1 – 2 cfm and task samples collected at about 20 cfm

High-volume and Low-volume Samplers

DWA Example Calculation

Job: Mill Operators | 1 Men/Shift | 2 Shifts/Day | 2 Men/Day

	Operation	Time (min)	Operations per Shift	Time per Shift	# of Samples	Conc. µg/m^3 Low	High	Avg	Conc. x Time
1	BZ Feeding Mill			60	6	0.2	9.8	4.5	270
2	BZ Removing Cover	6.4	1.5	9.6	4	2.9	5.8	4.3	41
3	BZ Process Samples	1	1.5	1.5	4	2.5	13	6.4	10
4	BZ Measure Samples	0.7	3	2.1	5	5.2	8.6	6.5	14
5	BZ Replace Cover	7.2	1.5	10.8	4	3.6	5.7	5	54
6	GA Mill Area			351	10	0.6	2.1	1.4	491
7	GA Leaching Area			20	7	0.6	12	2.8	56
8	GA Lunch Rm			30	7	0.04	2.7	0.8	24
9	GA Locker Rm			28	6	0.3	1.4	0.8	22

Total 513 DWA 1.9

Selected Operations
Median µg/m^3

- Metal Fabrication
  - Highest Task — Drilling — 8.9
  - Lowest Task — Cold Extrusion — 0.4
  - General Area — 0.6

- Beryllia
  - Highest Task — Jaw Crusher — 29
  - Lowest Task — Mixing slip — 0.5
  - General Area — 0.5

Lung Cancer Case-Control Study of Beryllium Workers
Sanderson WT, et al. Am J Ind Med. 2001

From Table II. Comparison of Geometric Mean Exposure Metrics of Cases and Controls by Various Beryllium Exposure Estimates.

	Cases	Controls
	n = 142	n=710
Average, $\mu g/m^3$	22.8	19.3
Maximum, $\mu g/m^3$	32.4	27.1

Estimating Historical Exposures of Workers in a Beryllium Manufacturing Plant
Sanderson WT, et al. Am J Ind Med. 2001

Job	Dates	Days	$\mu g/m^3$	$\mu g/m^3$ days
Laborer	8/8-10/11/47	64	250	1600
Furnace	- 2/23/48	135	131	17,685
Scarfer lathe	- 11/2/1948	253	25	6376
Laid off	- 3/16/1949	0	0	0
Scarfer lathe	- 7/10/1950	481	25	12,121
Extrusion	- 3/17/51	250	17	4250
Finish Mill	- 9/1/52	534	15	7903
Total		1717		49,935
		Lifetime Weighted (LTW) Mean		29
		Maximum		131

Calibration Factor for DWA

- DWA = Exp[-0.45 + 0.71 Ln(Total)]
- Correlation Coefficient R = 0.67
- If DWA = 20 then Total = 128
- If DWA = 2 then Total = 5

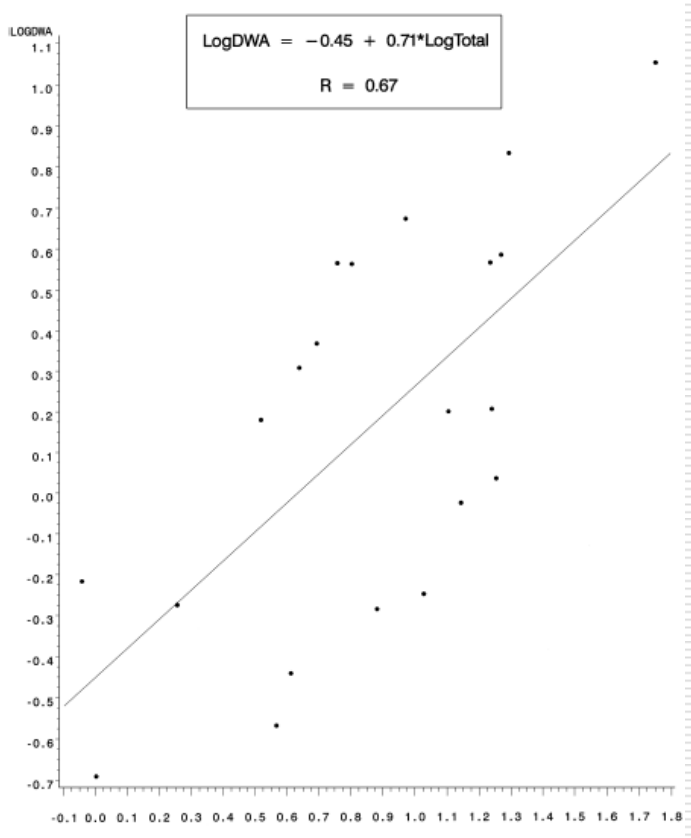


Figure 2. Regression of the log of DWA samples on the log of personal total samples.

Beryllium Sampling Methods

Donaldson and Stringer, NIOSH Report # 76-201 (1976)

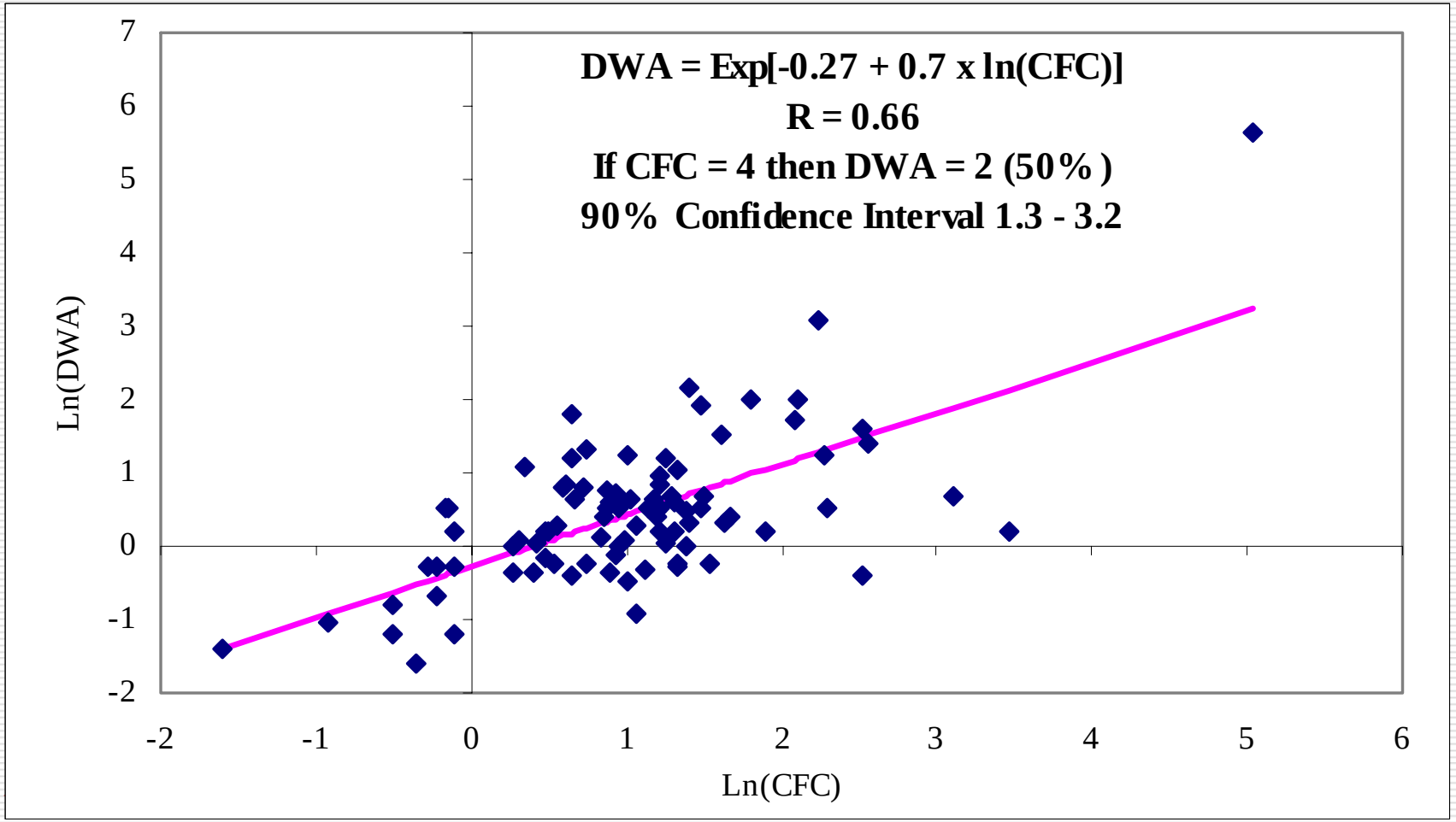
- Compares AEC DWA, Personal Total and Personal Respirable sampling methods
- Summarizes 18 survey reports over a 1 year period from 5 areas of a beryllium production plant
  1. Powder Metal Products
  2. Extraction Oxide
  3. Ceramics
  4. Alloy
  5. Maintenance (Furnace Rebuild)

Arithmetic Means (µg/m³) and Number of Samples – From Table 4

Area	Personal Total (CFC)	Personal Respirable (RPM)	AEC DWA	Number of Samples
1	5.2	1.02	1.55	105
2	2.63	1.4	1.75	144
3	1.69	0.75	1.03	36
4	5.09	1.58	2.93	54
5	12.96	3.59	19.18	18
Overall	4.18	1.36 (32%)	2.68 (64%)	357

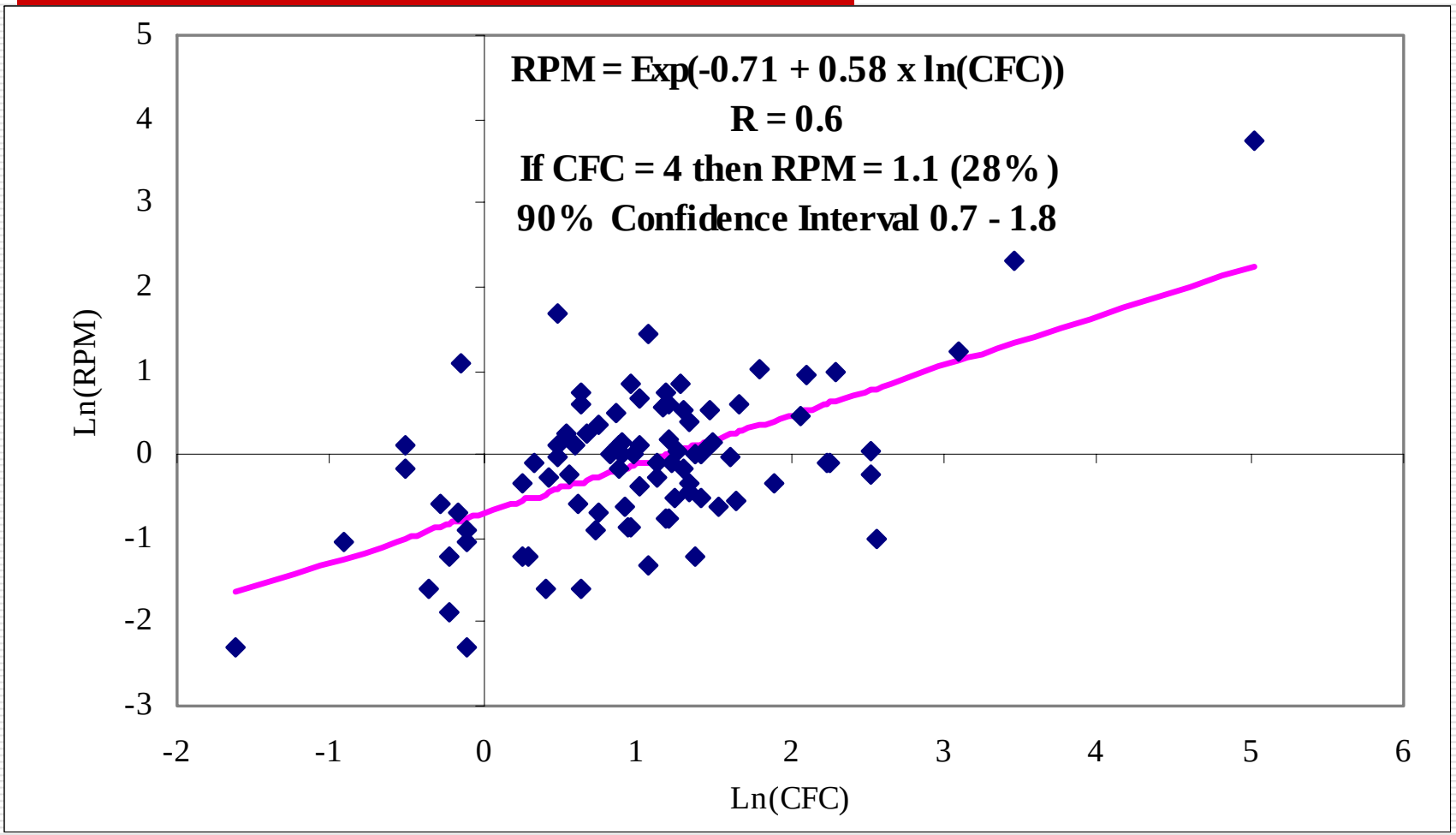
CFC vs DWA Line Fit Plot

Data from Table 3



CFC vs RPM Line Fit Plot

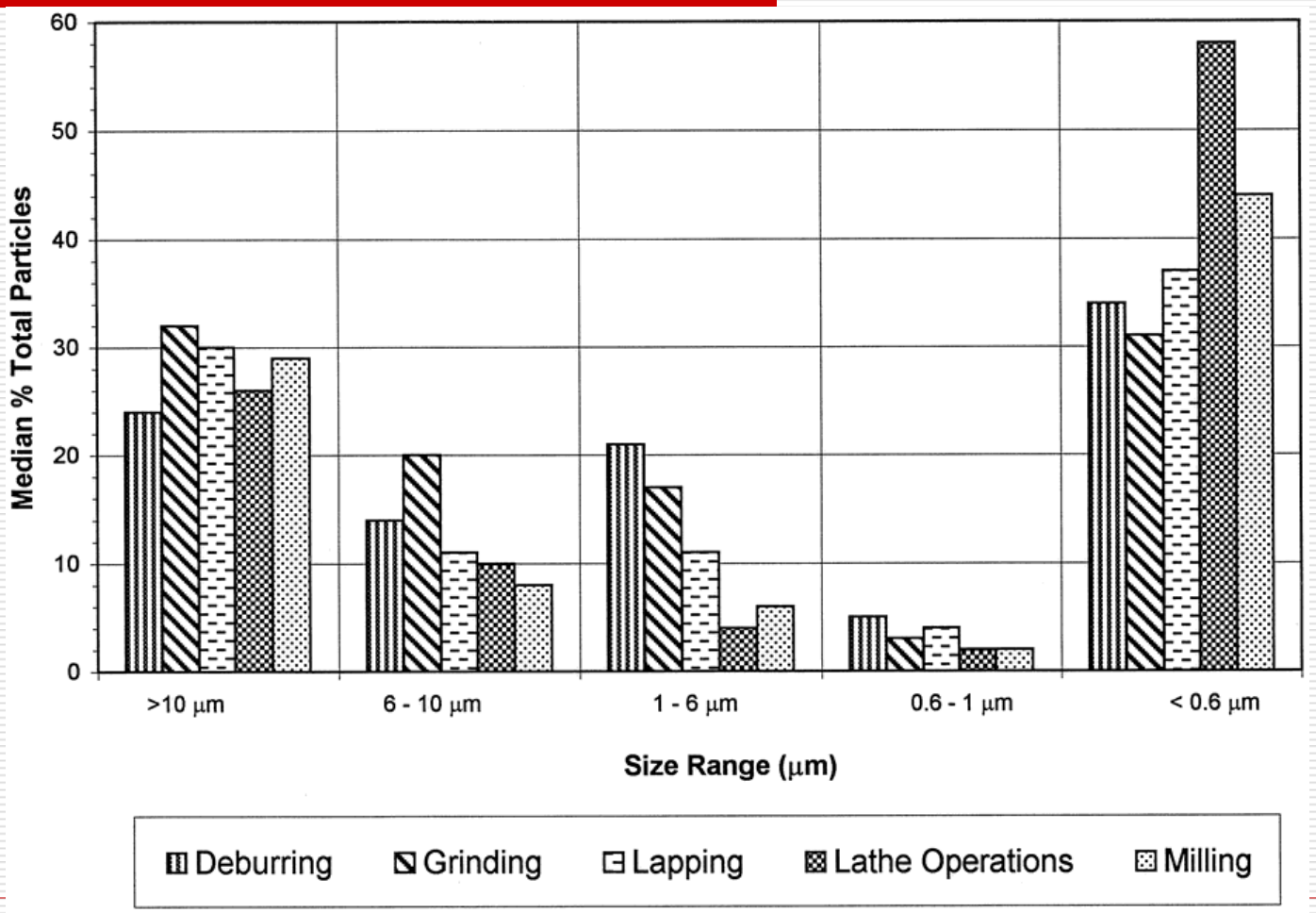
Data from Table 3



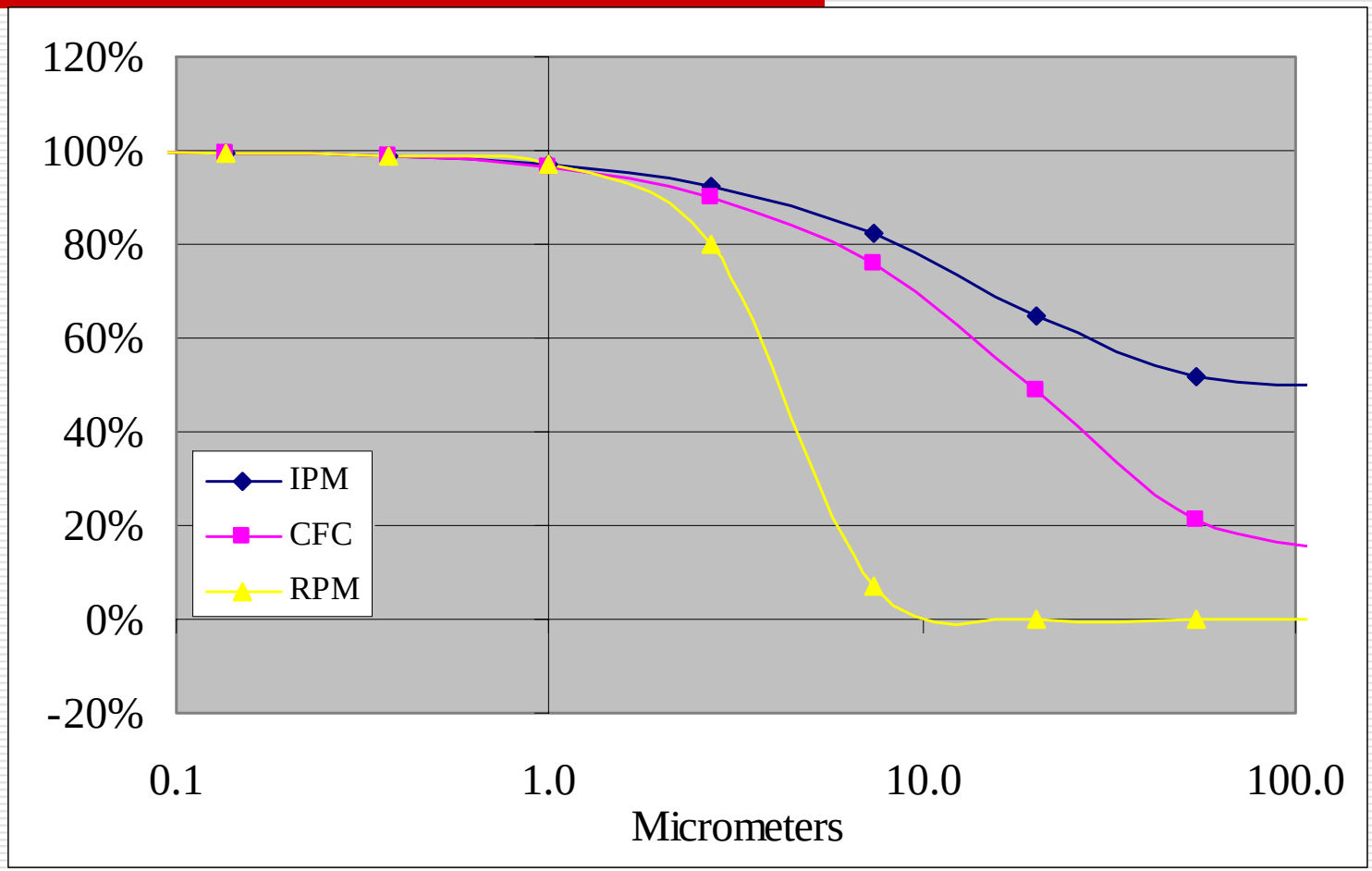
Size Selective Sampling

- Aerosols generated during beryllium machining.
  - Martyny JW, Hoover MD, Mroz MM, Ellis K, Maier LA, Sheff KL, Newman LS. J Occup Environ Med. 2000 Jan;42(1):8-18.
- A preliminary study of a beryllium processing facility.
  - Kent MS, Robins TG, Madl AK. Appl Occup Environ Hyg. 2001 May;16(5):539-58.

Martyny et al 2000
Beryllium Machining Plant



Theoretical Collection Efficiency of Aerosol Samplers



Relative Collection Efficiency of Air Samplers for Deburring Aerosols

µm	Total	IPM	Collected	RPM	Collected
> 10	24%	200%	48%	0%	0%
6 - 10	15%	100%	15%	5%	1%
1 - 6	21%	100%	21%	70%	15%
0.6 - 1	6%	100%	6%	98%	6%
< 0.6	34%	100%	34%	100%	34%
Sum	100%		124%		55%

Kent et al. 2001
Beryllium Production Plant

TABLE II

Median total mass concentration of Be particles by work process area and particle size collected with the Andersen impactor sampler at the Elmore facility (1997)

Process area	n	Median total mass concentration of Be particles ($\mu g/m^3$)							Cumulative mass of all Be particle sizes ($\mu g/m^3$)
		Particles >10 μm MMAD	Particles 10–6 μm MMAD	Particles 6–3.5 μm MMAD	Particles 3.5–2.0 μm MMAD	Particles 2.0–1.0 μm MMAD	Particles 1.0–0.6 μm MMAD	Particles 0.6–0.1 μm MMAD	
ABF and BeF_2 reduction furnace	26	1.3263	0.2195[A]	0.1492	0.1059[B]	0.0645[C]	0.0503[D]	0.0431[E]	1.9588
BeO furnace	11	4.3859	0.5432	0.3137	0.2101	0.1035[B]	0.0546[D]	0.0804[E]	5.6914
CuBe induction furnace	12	3.2573	0.5863[A]	0.3830	0.2153	0.0976[A]	0.0543[D]	0.2717[E]	4.8655
CuBe arc furnace	6	0.6031	0.1182[B]	0.0791[B]	0.0339[F]	0.0113[G]	0.0113[G]	0.0113[G]	0.8682

Relative Collection Efficiency of Air Samplers for ABF & BeF_2 Furnace Aerosols

µm	Total	IPM	Collected	RPM	Collected
> 10	68%	200%	135%	0%	0%
6 - 10	11%	100%	11%	5%	1%
3.5 - 6	8%	100%	8%	40%	3%
2 - 3.5	5%	100%	5%	80%	4%
1 - 2	3%	100%	3%	94%	3%
0.6 - 1	3%	100%	3%	98%	3%
< 0.6	2%	100%	2%	100%	2%
Sum	100%		168%		16%

Exposure Assessments of CBD and BeS Cases

- Ceramics Plant
  - Kreiss K, et al. Am J Ind Med. 1996 Jul;30(1):16-25.
  - Henneberger PK, et al. Int Arch Occup Environ Health. 2001 Apr;74(3):167-76.
- Rocky Flats Plant
  - Viet SM, et al. AIHAJ. 2000 Mar-Apr;61(2):244-54.
- Machining Plant
  - Kelleher PC, et al. J Occup Environ Med. 2001 Mar;43(3):238-49.
  - Madl AK, et al. Occup Environ Hyg. 2007 Jun;4(6):448-66.
- Alloy Plant
  - Schuler CR, et al. Am J Ind Med. 2005 Mar;47(3):195-205.

Ceramics Plant
Kreiss K, et al. 1996

- Found 6 CBD and 2 BeS cases
- JEM used DWA and Personal CFC measurements
  - 4890 general area, 4133 high-volume BZ and 75 personal samples.
  - "No difference existed between the average personal lapel samples (median = 0.20, range 0.1 – 1.5 µg/m^3) and corresponding DWA estimates (0.20 µg/m^3, range 0.1 – 1.9) . . ."
- LTW means for cases:
  - range 0.2 to 1.1 µg/m^3
  - median of 0.55 µg/m^3

Ceramics Plant

Henneberger PK, et al. 2001

- Found 15 new cases of BeS and CBD
- LTW means for 8 long-term workers:
  - range 0.17 to 2.16 µg/m^3
  - median of 0.4 µg/m^3
- LTW means for 7 short-term workers (< 2 yrs),
  - range 0.05 to 4.4 µg/m^3
  - median 0.38 µg/m^3

Rocky Flats Plant

Viet SM, et al. 2000

- Retrospective exposure assessment of 50 CBD cases, 74 BeS cases and equal numbers of controls.
- Utilized fixed airhead (FAH) monitoring results to estimate mean exposure levels in locations cases and controls worked.
- Estimated that personal CFC results are about 10 times higher than FAH monitoring results.
- Median LTW FAH levels were estimated to be:
  - 0.063 µg/m^3 for CBD cases;
  - 0.022 µg/m^3 for BeS cases;
  - 0.015 µg/m^3 for controls matched to CBD cases; and
  - 0.012 µg/m^3 for controls matched to BeS cases.

Machining Plant
Kelleher PC, et al. 2001

- 20 workers diagnosed with BeS or CBD
- Estimates Based on:
  - 100 personal impactor samples 1996–99
  - 649 personal CFC samples 1981–84 & 1995-99
  - 140 historical general area samples
- LTW means for cases
  - range 0.024 – 0.6 µg/m^3
  - median 0.39 µg/m^3
- No workers among 22 with LTW mean exposures less than 0.02 µg/m^3 had BeS

Machining Plant
Madl AK, et al. 2007

- 20 BeS and CBD cases reported by Kelleher et al. plus an additional 7 cases
- Based on additional 3831 personal CFC and 616 general area samples
- LTW means for cases
  - Range 0.09 to 7.89 µg/m^3
  - Median of 0.41 µg/m^3

Alloy Plant
Schuler CR, et al. 2005

- Found 6 BeS and 10 CBD cases, all associated with a high risk area
- 210 personal CFC samples from the high risk area
  - Median of 0.06 µg/m^3
  - 95-95 UTL of 0.68 µg/m^3
  - Estimate a mean of 0.14 µg/m^3
- 320 personal CFC samples in low risk areas
  - Median 0.02 µg/m3
  - 95-95 UTL of 0.1 µg/m3
  - Estimate a mean of 0.03 µg/m^3
- Older general area monitoring indicate levels were higher in the past

Summary

Reference	Median LTW Mean µg/m^3	Notes
Kreiss 1996	0.55	8 CBD and BeS Cases
Henneberger 2001	0.38	15 BeS and CBD Cases
Viet 2000	0.63	50 CBD cases, FAH monitoring
	0.22	74 BeS cases
Kelleher 2001	0.39	20 BeS and CBD cases.
	0.02	No BeS for group of 20 workers
Madl 2007	0.41	27 BeS and CBD cases.
	Mean Level µg/m^3	
Eisenbud 1949	0.4	8-Hr TWA with CBD (from ambient
	0.04	8-Hr TWA no CBD air monitoring)
Schuler 2005	0.14	8-Hr TWA with CBD
	0.03	8-Hr TWA no CBD

Conclusions

- Historical monitoring results are rough risk indicators. There is no compelling reason to maintain continuity
- Mean beryllium exposure levels of about 0.5 µg/m^3 are associated with CBD – personal CFC sampling
  - Mean levels should be controlled to less than 0.05 µg/m^3
  - Could be achieved with high rate of compliance with limits higher than this
- Sampling and analytical methods capable of detecting 5 ng/m^3 would be desirable
- For size selective sampling detecting 1 ng/m^3 would be desirable