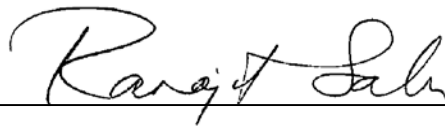


**Eskom's Kendal Power Station Exceedances of  
Applicable Atmospheric Emission License Limit Values  
for Particulate Matter from April 2016 to March 2020**

April 24, 2020

**Dr. Ranajit (Ron) Sahu, Ph.D., QEP, CEM**  
**Consultant, Energy & Air Quality Issues**  
**Alhambra, CA**



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**Summary**

At the request of Centre for Environmental Rights, I reviewed monthly emissions reports from Eskom's Kendal Power Station where reports have been made available, from April 2016 through March 2020, the most recent report as of the date of this report (i.e., 47 months). Only December 2019 was not available. The monthly emissions reports revealed that:

- In that time period, Kendal Power Station had **2,712 exceedances** of its Atmospheric Emission License (AEL) limit of 100 mg/Nm<sup>3</sup> for average daily particulate matter (PM) emissions ("PM limit")
- PM exceedances became **three times more frequent starting in April 2018, and have never returned to pre-April 2018 frequencies**. January 2020 had the most PM exceedances of any month (151).
- **In 2019, 83% of exceedances were twice the PM limit**. 35% of 2019 exceedances were four times the PM limit, while 10% were 12 times the PM limit. In 2018, 2% of exceedances were 25 times the PM limit. From 2016 to 2020, between six and nine percent of PM exceedances were 12 times the PM limit. For the three months of data available for 2020, 84% of exceedances were twice the PM limit; 31% were four times the limit, and 6% were 12 times the limit.
- In the most recent report of March 2020, even with Unit 5 shut down, the remaining units exceeded the PM limit 88 times. 24% of operating days at Unit 6 emitted PM at 10 times the PM limit (over 1000 mg/Nm<sup>3</sup>).
- The data indicate that the electrostatic precipitators at all units at the Kendal Power Station are simply not working properly, even after maintenance on the precipitators is purportedly complete. I recommend that Kendal Power Station **either shut down or that all units be rapidly retrofitted with properly designed fabric filters** to effectively control particulate matter emissions and improve regional air quality and public health. Such retrofitting would enable Kendal Power Station to not only meet its AEL limits, it would also meet the World Bank recommended limits for maximum PM emissions for large power plants in degraded airsheds (25 mg/Nm<sup>3</sup>).

## **Background**

Eskom's Power Stations produce monthly hardcopy emissions monitoring reports with graphs of average daily emissions of SO<sub>2</sub>, NO<sub>x</sub>, and PM for each unit. Kendal Power Station, located roughly 40 km southwest of Witbank, Mpumalanga, has six units each 686 MW in size, with a combined installed capacity of 4,116 MW. It was completed in 1993.<sup>1</sup>

Eskom provided the 2016 and 2017 monthly emission reports for Kendal Power Station to the Centre for Environmental Rights following a freedom of information request. The 2018, 2019 and 2020 reports, with the exception of December 2019, are available on Eskom's website.<sup>2</sup>

I accepted the reported data as accurate, as I do not have the capability to independently confirm the reported data. I assume that the monitors used to measure pollutant levels were being calibrated and maintained as required, unless explicitly noted.

From April 2016 through July 2019, the monthly emissions reports used three categories of emissions for each day: Raw, Final, and/or Section 30. I tallied only Final exceedances of the AEL limit, not Raw or Section 30 exceedances. (There is no explanation why some days and not others are coded as relevant to Section 30 of the National Environmental Management Act.)

Beginning in August 2019, the graphs in the monthly reports did away with Raw and Final coding, and presented only one emission type per day, which I have to presume is equivalent to Final in the prior reports. The graphs categorized the emissions as Normal, Grace, Contravention, or Section 30. The monthly reports also began including a table (Table 6.2) with tallies of exceedances by these new types, as well as a monthly average of the daily PM emissions at each unit.

The opinions provided in this report are based on my education, professional training, and twenty-eight years of experience in air pollution consulting and engineering, on behalf of clients in the private and public sector in the United States and internationally. Details of my experience are provided in my vitae provided in Attachment A.

## **Methodology**

I quantified the number of days during a period of 47 consecutive months (April 2016 through March 2020) where reported emissions clearly exceeded the AEL limit value of 100 mg/Nm<sup>3</sup>. I took a conservative approach in that I did not count concentrations that just reached (but did not clearly exceed) the AEL limit value, or where the graphs were too small to be easily readable. I

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<sup>1</sup>[http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Coal/Pages/Kendal\\_Power\\_Station.aspx](http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Coal/Pages/Kendal_Power_Station.aspx).

<sup>2</sup> <http://www.eskom.co.za/Whatweredoing/AirQuality/Pages/Kendal-Power-Station.aspx>.

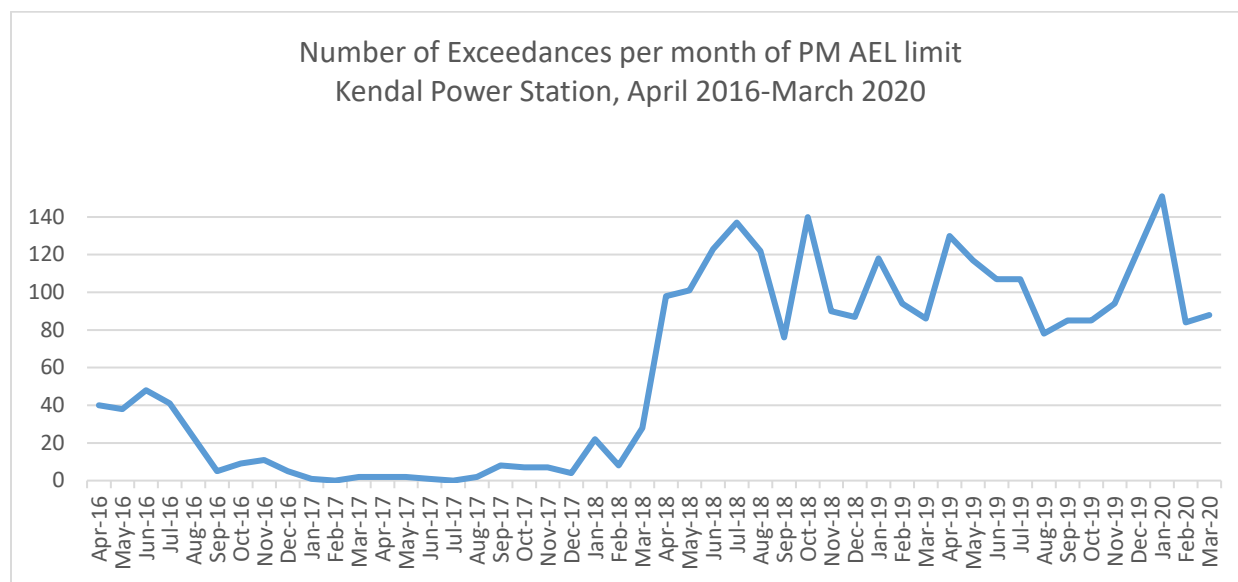
also quantified how many daily average emissions reached or exceeded<sup>3</sup> various concentrations each month. I then calculated what percentage of exceedances reached or exceeded various concentrations each year and cumulatively over the 47-month period.

Because most months reported had few if any SO<sub>2</sub> or NO<sub>x</sub> emission limit exceedances at Kendal, I did not tally those, as they appear insignificant compared to the PM emissions exceedances at Kendal, or to the SO<sub>2</sub> and NO<sub>x</sub> AEL exceedances at other Eskom plants.<sup>4</sup>

For the reasons stated, my analysis is conservative and likely underestimates the true scope of the exceedances at Kendal, since the monthly reports do not provide clear and comprehensive data. For example, the graphs in some reports are blurry when enlarged. There are many days where Final data are simply missing, even though Raw data suggest an exceedance likely occurred.

### **Findings & Analysis**

1. Based on my analysis, Kendal Power Station reported 2,712 violations of its applicable AEL limit for PM between April 2016 and March 2020 (47 months). The plant reported 220 PM exceedances in 2016 (9 months); 36 exceedances in 2017 (12 months); 1,035 exceedances in 2018 (12 months); 1,097 in 2019 (11 months); and 323 exceedances in 2020 (3 months). January 2020 had the highest number of exceedances. See Appendix I for full results.

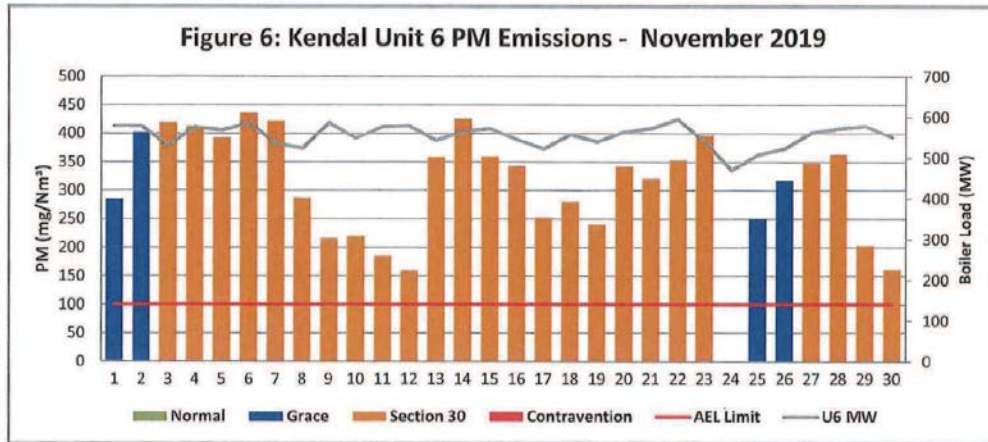


**Figure 1.** Monthly exceedances of air emissions licence (AEL) limits for particulate matter (PM) at Kendal Power Station starting April 2016 through March 2020 (missing December 2019).

<sup>3</sup> Due to low resolution of graphs, it was difficult to determine if exceedances above 100 mg/Nm<sup>3</sup> reached or exceeded higher values where no horizontal lines were present on the graphs. To be conservative, I describe these exceedances as “were x% of the AEL limit”.

<sup>4</sup> See, e.g. R. Sahu, *Eskom Power Station Exceedances of Applicable Atmospheric Emission License (AEL) Limit Values for PM, SO<sub>2</sub> & NO<sub>x</sub> During April 2016 to December 2017* (2019), <https://cer.org.za/wp-content/uploads/2019/04/Ron-Sahu-Eskom-Exceedances-Report-updated-March-22-2019.pdf>.

2. Kendal Power Station exceeded its PM licence limit in 96% of the reported months (45/47), and in 100% of the reported months in 2018, 2019, and 2020 (26/26).
3. PM exceedances became three times more frequent between March and April 2018, and never returned to pre-April 2018 levels.
4. October 2018 had the highest daily average PM emissions, reaching or exceeding 2,500 mg/Nm<sup>3</sup>, or 25 times the legal limit, on 16 days.
5. January 2020 had the most PM exceedances of any month (151 exceedances). In the three reported months of 2020, 84% of exceedances reached or exceeded twice the AEL limit; 31% reached or exceeded four times the AEL limit; 6% reached or exceeded 12 times the AEL limit.
6. In 2019, 83% of exceedances reached or exceeded twice the permitted limit; 35% reached or exceeded four times the limit; and 10% reached or exceeded twelve times the limit.
7. In 2018, 50% of exceedances reached or exceeded twice the limit; 10% reached or exceeded ten times the permitted limit; 2% of exceedances reached or exceeded 25 times the AEL limit.
8. There is no clear seasonal pattern to the exceedances. In 2016, exceedances occurred more between April and August. In 2017, exceedances occurred more between September and November. After April 2018, the number exceedances varied between 70 to 151 each month through March 2020 (noting data for December were not available).
9. Various units were taken offline for entire months, which did not necessarily reduce exceedances. For example, Unit 5 was taken offline after August 2019, but total exceedances continued to increase in September, October and November 2019. Unit 5 was taken offline again in February and March 2020, but units 3, 4 and 6 all had dozens of exceedances each. In March 2020, Unit 6 had daily average emissions over 1000 mg/Nm<sup>3</sup> (10 times the AEL limit) on 6 days.
10. To the extent that the emissions data are affected by non-normal operating periods – such as startup or shutdown events; or periods that meet Section 30 criteria – these should be clearly and separately noted in the monthly report data – including any applicable time periods where such exemptions may apply. The monthly reports do not clarify why Section 30 exceedances continue for many consecutive days without the unit being shut down or serviced. For example, see Figure 2, below.



**Figure 2.** Kendal’s PM emissions at Unit 6 exceeded its AEL limit every day of operation during November 2019. There is no explanation why many consecutive days are coded as Section 30.

11. In the monthly reports from August through March 2020, not a single day of exceedance was marked as Contravention – all were coded as Grace or Section 30 without sufficient explanation. For example, in August 2019, Unit 1, with ESP utilization at 99.2%, had 15 days in Grace outside of startup/shutdown conditions, with daily averages nearing 1,000 mg/Nm<sup>3</sup>, with no explanation. Across all units, the power station had 49 Grace exceedances for the month, with no explanation of why these exceedances should be considered Grace rather than Contravention.
12. It is concerning that, in the monthly emissions reports from August through November 2019, the total PM exceedances for all units were incorrectly summed in all reports in Table 6.2, resulting in underreporting ranging from 24 to 30 below actual exceedances. (See Appendix II.) This problem did not recur in the 2020 reports.
13. Eskom has reported that Kendal Power Station does not have baghouses or fabric filters.<sup>5</sup> Clearly such pollution control technologies are urgently needed, as the electrostatic precipitators are not functioning appropriately, even when units are taken offline and maintenance is purportedly conducted. For example, in July 2018, with 137 exceedances, all units had ESPs operating over 99% of the time. In October 2018, with 140 exceedances, ESPs were reportedly operating at most units above 95% of the time. At Unit 3 in October 2018, the ESP was reportedly used 89% of the time, but emissions exceeded a daily average value of 2,500 mg/Nm<sup>3</sup> on over half the days of the month (16 days.)
14. The purpose of exceedance reporting is to identify the causes of exceedances, and implement actions to mitigate underlying causes. I do not see evidence of such analysis

<sup>5</sup> Eskom, *Applications For Postponement of the Minimum Emissions Standards (MES) for Eskom’s Coal and Liquid Fuel-Fired Power Stations Document Version: V004* (2014) at 6.

or actions by the operator of the Kendal Power Station. It goes without saying that every effort should be made to eliminate emissions exceedances in heavily populated areas already impaired by air pollution. The World Bank Group guidelines recommend limiting PM emissions from new Power Stations over 600 MWth in degraded airsheds to daily averages less than 25 mg/Nm<sup>3</sup>.<sup>6</sup> This emissions limit is achievable even at existing power stations with installations of fabric filters.

15. As noted prior, my analysis was limited by inconsistent and unclear reporting. When faced with uncertainty, I gave the benefit of the doubt to Eskom, and so my estimates likely underrepresent the extent of the exceedances. More accurate and comprehensive reporting would significantly enhance government enforcement of AELs and public scrutiny of power plant compliance. To that end, I have the following recommendations:
  - a. The data should be reported and made available to the public electronically (i.e., in Excel, ASCII or similar format). Using hardcopy reports is not necessary in our time. If needed at all, they should be provided in addition to electronic data. Not only are many of the hardcopy reports difficult to read, they pose an unnecessary hurdle to understanding the ongoing compliance problems at Kendal.
  - b. To the extent that any of the data are affected by performance issues with the monitoring equipment – i.e., CEMS malfunctions – those should be separately noted in the electronic data files.
  - c. The connection between Raw and Final emission data in the April 2016 through March 2019 reports is not clear. Any adjustments to Raw data that are made by the power plant operator to obtain the Final data should be clearly explained and noted in the electronic report. Deviations between Raw and Final data should be clearly explained. Grace, Section 30, and Contravention distinctions should also be clarified in the monthly reports.
  - d. If hardcopy reports are still needed, the format should be standardized. Currently, the types of information reported, the manner in which they are reported, and the degree to which the reported data are properly reviewed are insufficient. I recommend that the format for each report be made standard including what information should be reported on a mandatory basis (daily emissions, energy, capacity, CEMS malfunction periods, periods of startup and shutdown, Section 30 periods, etc. as noted earlier) or voluntary basis (coal

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<sup>6</sup> World Bank/IFC, *Environmental, Health, and Safety Guidelines for Thermal Power Plants*, Table 6, p. 35 (2017), <https://www.ifc.org/wps/wcm/connect/9ec08f40-9bc9-4c6b-9445-b3aed5c9afad/Thermal+Power+Guideline+2017+clean.pdf?MOD=AJPERES&CVID=INwcJZX>.

input data, heat input data, etc.). The format for hardcopy reporting should be specified by the regulator.

17. Based on this analysis of its emissions performance (or lack thereof) I recommend that the Kendal Power Station either simply shut down or be rapidly retrofitted with fabric filters at all six units to effectively control particulate matter emissions and improve regional air quality and public health.

## Appendix I. Tally of AEL PM Exceedances and Emissions Values at Kendal Power Station

These tables show the number of exceedances of daily average emissions of particulate matter at various concentrations at the six units of Eskom's Kendal Power Station, Mpumalanga, per month, from April 2016 through March 2020 (47 consecutive months, with only December 2019 not available). Data were tabulated from Eskom monthly reports. 100 mg/Nm<sup>3</sup> is the limit in the power station's air emissions license.

Ave. daily PM (mg/Nm <sup>3</sup> )	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
100	No report	No report	No report	40	38	48	41	23	5	9	11	5
150				10	6	10	13	4		2	1	1

Ave. daily PM (mg/Nm <sup>3</sup> )	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
100	1	0	2	2	2	1	0	2	8	7	7	4
150			1		2			0	1	2	2	
200					1							

Ave. daily PM (mg/Nm <sup>3</sup> )	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18
100	22	8	28	98	101	123	137	122	76	140	90	87
150	2	0	6	42	63	103	119	112	21	124	42	72
200	1		1	20	34	87	90	103	1	115	26	63
400				5	7	52	44	65		90	26	19
600				3	7	20	17	32		60	21	17
800				1	2	18	6	16		56	19	17
1000				1	1	18	6	16		55	13	10
1200				1		14	5			45	6	2
1400				1		6	2			25		
1600				1		6	2			21		
1800						6	2			21		
2000						6				21		
2500						1				16		

Ave. daily PM (mg/Nm <sup>3</sup> )	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
100	118	94	86	130	117	107	107	74	85	85	94	NA
150	102	89	81	124	115	94	98	74	81	71	81	
200	91	85	78	120	111	92	94	67	64	53	63	
400	39	32	31	78	53	50	52	36	4	4	7	



<b>600</b>	22	13	26	53	32	15	17	10				
<b>800</b>	22	13	19	46	19	7	15	9				
<b>1000</b>	22	12	15	42	18	1	15	7				
<b>1200</b>	19	9	14	39	12		15	7				
<b>1400</b>				18	6							
<b>1600</b>				2								

Ave. daily PM (mg/Nm <sup>3</sup> )	Jan-20	Feb-20	Mar-20
<b>100</b>	151	84	88
<b>150</b>	150	84	68
<b>200</b>	143	78	51
<b>400</b>	51	73	15
<b>600</b>	18		13
<b>800</b>	18		9
<b>1000</b>	18		6
<b>1200</b>	18		

Ave. daily PM (mg/N m <sup>3</sup> )	2016 Total (9 mos)	% of exceed-ances	2017 Total (12 mos)	%	2018 Total (12 mos)	%	2019 Total (11 mos)	%	2020 Total (3 mos)	%	Grand Total (47 mos)	%
<b>100</b>	<b>220</b>		<b>36</b>		<b>1032</b>		<b>1424</b>		<b>323</b>		<b>2712</b>	
<b>150</b>	47	21%	8	22%	706	68%	1312	71%	302	93%	<b>2073</b>	76%
<b>200</b>			1	3%	541	52%	1190	84%	272	84%	<b>1732</b>	64%
<b>400</b>					308	30%	525	37%	139	43%	<b>833</b>	31%
<b>600</b>					177	17%	219	15%	31	10%	<b>396</b>	15%
<b>800</b>					135	13%	177	12%	27	8%	<b>312</b>	12%
<b>1000</b>					120	12%	156	11%	24	7%	<b>276</b>	10%
<b>1200</b>					73	7%	133	9%	18	6%	<b>206</b>	8%
<b>1400</b>					34	3%	24	2%	0	0%	<b>58</b>	2%
<b>1600</b>					30	3%	2	0%	0		<b>32</b>	1%
<b>1800</b>					29	3%					<b>29</b>	1%
<b>2000</b>					27	3%					<b>27</b>	1%
<b>2500</b>					17	2%					<b>17</b>	1%

**Appendix II. Kendal Power Station underreported PM exceedances in August, September, October and November 2019 monthly emission reports' Tables 6.2.**

Table 6.2 Operating days in compliance to PM AEL Limit - August 2019

Associated Unit/Stack	Normal	Grace	Section 30	Contra-vention	Total Exceedance	Average PM (mg/Nm <sup>3</sup> )
Unit 1	10	16	0	0	16	255.9
Unit 2	0	0	0	0	0	
Unit 3	0	19	0	0	19	256.1
Unit 4	0	14	0	0	14	343.6
Unit 5	0	7	0	0	7	1302.8
Unit 6	0	23	0	0	23	438.6
SUM	10	49	0	0	49	

*Figure 1. In the August 2019 report, Table 6.2, the PM exceedances by unit are correct but the sums are not: correct Grace and Total exceedances in August 2019 sum to 79, not 49, as reported. Thus PM exceedances for August 2019 were underreported by 30 without explanation.*

Table 6.2 Operating days in compliance to PM AEL Limit - September 2019

Associated Unit/Stack	Normal	Grace	Section 30	Contra-vention	Total Exceedance	Average PM (mg/Nm <sup>3</sup> )
Unit 1	16	5	0	0	5	83.6
Unit 2	0	0	0	0	0	
Unit 3	0	3	24	0	27	216.2
Unit 4	0	2	29	0	31	283.2
Unit 5	0	0	0	0	0	
Unit 6	0	2	22	0	24	326.0
SUM	16	10	53	0	63	

*Figure 2. In the September 2019 report, Table 6.2, the PM exceedances by unit are correct but the sums are not: Grace sums to 12, not 10. Section 30 sums to 75, not 53. Total sums to 87, not 63 as reported. Thus PM exceedances for September 2019 were underreported by 24 without explanation.*

Table 6.2 Operating days in compliance to PM AEL Limit - October 2019

Associated Unit/Stack	Normal	Grace	Section 30	Contra-vention	Total Exceedance	Average PM (mg/Nm <sup>3</sup> )
Unit 1	16	7	8	0	15	120.0
Unit 2	0	0	0	0	0	
Unit 3	0	2	29	0	31	219.5
Unit 4	2	4	10	0	14	270.5
Unit 5	0	0	0	0	0	
Unit 6	0	3	22	0	25	281.8
SUM	18	13	47	0	60	

**Figure 3.** In the October 2019 report, Table 6.2, the exceedances by unit are correct but the sums are not: Grace sums to 16, not 13. Section 30 sums to 69, not 47. Total sums to 85, not 60 as reported. Thus exceedances for October 2019 were underreported by 25 without explanation.

Table 6.2 Operating days in compliance to PM AEL Limit - November 2019

Associated Unit/Stack	Normal	Grace	Section 30	Contra-vention	Total Exceedance	Average PM (mg/Nm <sup>3</sup> )
Unit 1	6	12	10	0	22	159.8
Unit 2	11	3	1	0	4	89.4
Unit 3	0	4	19	0	23	260.3
Unit 4	4	8	12	0	20	166.9
Unit 5	0	0	0	0	0	
Unit 6	0	4	25	0	29	315.7
SUM	21	27	42	0	69	

**Figure 4.** In the November 2019 report, Table 6.2, the exceedances by unit are correct but the sums are not: Grace sums to 31, not 27. Section 30 sums to 67, not 42. Total sums to 94, not 69. Thus exceedances for November 2019 were underreported by 25 without explanation.

# **Attachment A**

## **Vitae**

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### **EXPERIENCE SUMMARY**

Dr. Sahu has over 30 years of experience in the fields of environmental, mechanical, and chemical engineering including: program and project management services; design and specification of pollution control equipment for a wide range of emissions sources including stationary and mobile sources; soils and groundwater remediation including landfills as remedy; combustion engineering evaluations; energy studies; multimedia environmental regulatory compliance (involving statutes and regulations such as the Federal CAA and its Amendments, Clean Water Act, TSCA, RCRA, CERCLA, SARA, OSHA, NEPA as well as various related state statutes); transportation air quality impact analysis; multimedia compliance audits; multimedia permitting (including air quality NSR/PSD permitting, Title V permitting, NPDES permitting for industrial and storm water discharges, RCRA permitting, etc.), multimedia/multi-pathway human health risk assessments for toxics; air dispersion modeling; and regulatory strategy development and support including negotiation of consent agreements and orders.

He has over 25 years of project management experience and has successfully managed and executed numerous projects in this time period. This includes basic and applied research projects, design projects, regulatory compliance projects, permitting projects, energy studies, risk assessment projects, and projects involving the communication of environmental data and information to the public.

He has provided consulting services to numerous private sector, public sector and public interest group clients. His major clients over the past twenty five years include various trade associations as well as individual companies such as steel mills, petroleum refineries, cement manufacturers, aerospace companies, power generation facilities, lawn and garden equipment manufacturers, spa manufacturers, chemical distribution facilities, and various entities in the public sector including EPA, the US Dept. of Justice, several states, various agencies such as the California DTSC, various municipalities, etc.). Dr. Sahu has performed projects in all 50 states, numerous local jurisdictions and internationally.

In addition to consulting, Dr. Sahu has taught numerous courses in several Southern California universities including UCLA (air pollution), UC Riverside (air pollution, process hazard analysis), and Loyola Marymount University (air pollution, risk assessment, hazardous waste management) for the past seventeen years. In this time period he has also taught at Caltech, his alma mater (various engineering courses), at the University of Southern California (air pollution controls) and at California State University, Fullerton (transportation and air quality).

Dr. Sahu has and continues to provide expert witness services in a number of environmental areas discussed above in both state and Federal courts as well as before administrative bodies (please see Annex A).

### **EXPERIENCE RECORD**

2000-present **Independent Consultant.** Providing a variety of private sector (industrial companies, land development companies, law firms, etc.) public sector (such as the US Department of Justice) and public interest group clients with project management, air quality consulting, waste remediation and management consulting, as well as regulatory and engineering support consulting services.

1995-2000 **Parsons ES, Associate, Senior Project Manager and Department Manager for Air Quality/Geosciences/Hazardous Waste Groups, Pasadena.** Responsible for the management of a group of approximately 24 air quality and environmental professionals, 15 geoscience, and 10 hazardous waste professionals providing full-service consulting, project management, regulatory compliance and A/E design assistance in all areas.

Parsons ES, **Manager for Air Source Testing Services.** Responsible for the management of 8 individuals in the area of air source testing and air regulatory permitting projects located in Bakersfield, California.

1992-1995 **Engineering-Science, Inc. Principal Engineer and Senior Project Manager** in the air quality department. Responsibilities included multimedia regulatory compliance and permitting (including hazardous and nuclear materials), air pollution engineering (emissions from stationary and mobile sources, control of criteria and air toxics, dispersion modeling, risk assessment, visibility analysis, odor analysis), supervisory functions and project management.

1990-1992 **Engineering-Science, Inc. Principal Engineer and Project Manager** in the air quality department. Responsibilities included permitting, tracking regulatory issues, technical analysis, and supervisory functions on numerous air, water, and hazardous waste projects. Responsibilities also include client and agency interfacing, project cost and schedule control, and reporting to internal and external upper management regarding project status.

- 1989-1990 Kinetics Technology International, Corp. **Development Engineer.** Involved in thermal engineering R&D and project work related to low-NOx ceramic radiant burners, fired heater NOx reduction, SCR design, and fired heater retrofitting.
- 1988-1989 Heat Transfer Research, Inc. **Research Engineer.** Involved in the design of fired heaters, heat exchangers, air coolers, and other non-fired equipment. Also did research in the area of heat exchanger tube vibrations.

### EDUCATION

- 1984-1988 Ph.D., Mechanical Engineering, California Institute of Technology (Caltech), Pasadena, CA.
- 1984 M. S., Mechanical Engineering, Caltech, Pasadena, CA.
- 1978-1983 B. Tech (Honors), Mechanical Engineering, Indian Institute of Technology (IIT) Kharagpur, India

### TEACHING EXPERIENCE

#### Caltech

"Thermodynamics," Teaching Assistant, California Institute of Technology, 1983, 1987.

"Air Pollution Control," Teaching Assistant, California Institute of Technology, 1985.

"Caltech Secondary and High School Saturday Program," - taught various mathematics (algebra through calculus) and science (physics and chemistry) courses to high school students, 1983-1989.

"Heat Transfer," - taught this course in the Fall and Winter terms of 1994-1995 in the Division of Engineering and Applied Science.

"Thermodynamics and Heat Transfer," Fall and Winter Terms of 1996-1997.

#### U.C. Riverside, Extension

"Toxic and Hazardous Air Contaminants," University of California Extension Program, Riverside, California. Various years since 1992.

"Prevention and Management of Accidental Air Emissions," University of California Extension Program, Riverside, California. Various years since 1992.

"Air Pollution Control Systems and Strategies," University of California Extension Program, Riverside, California, Summer 1992-93, Summer 1993-1994.

"Air Pollution Calculations," University of California Extension Program, Riverside, California, Fall 1993-94, Winter 1993-94, Fall 1994-95.

"Process Safety Management," University of California Extension Program, Riverside, California. Various years since 1992-2010.

"Process Safety Management," University of California Extension Program, Riverside, California, at SCAQMD, Spring 1993-94.

"Advanced Hazard Analysis - A Special Course for LEPCs," University of California Extension Program, Riverside, California, taught at San Diego, California, Spring 1993-1994.

"Advanced Hazardous Waste Management" University of California Extension Program, Riverside, California. 2005.

#### Loyola Marymount University

"Fundamentals of Air Pollution - Regulations, Controls and Engineering," Loyola Marymount University, Dept. of Civil Engineering. Various years since 1993.

"Air Pollution Control," Loyola Marymount University, Dept. of Civil Engineering, Fall 1994.

"Environmental Risk Assessment," Loyola Marymount University, Dept. of Civil Engineering. Various years since 1998.

"Hazardous Waste Remediation" Loyola Marymount University, Dept. of Civil Engineering. Various years since 2006.

#### University of Southern California

"Air Pollution Controls," University of Southern California, Dept. of Civil Engineering, Fall 1993, Fall 1994.

"Air Pollution Fundamentals," University of Southern California, Dept. of Civil Engineering, Winter 1994.

#### University of California, Los Angeles

"Air Pollution Fundamentals," University of California, Los Angeles, Dept. of Civil and Environmental Engineering, Spring 1994, Spring 1999, Spring 2000, Spring 2003, Spring 2006, Spring 2007, Spring 2008, Spring 2009.

#### International Programs

"Environmental Planning and Management," 5 week program for visiting Chinese delegation, 1994.

"Environmental Planning and Management," 1 day program for visiting Russian delegation, 1995.

"Air Pollution Planning and Management," IEP, UCR, Spring 1996.

"Environmental Issues and Air Pollution," IEP, UCR, October 1996.

**PROFESSIONAL AFFILIATIONS AND HONORS**

President of India Gold Medal, IIT Kharagpur, India, 1983.

Member of the Alternatives Assessment Committee of the Grand Canyon Visibility Transport Commission, established by the Clean Air Act Amendments of 1990, 1992-present.

American Society of Mechanical Engineers: Los Angeles Section Executive Committee, Heat Transfer Division, and Fuels and Combustion Technology Division, 1987-present.

Air and Waste Management Association, West Coast Section, 1989-present.