TOXICOLOGICAL EVALUATION OF REALISTIC EMISSIONS OF SOURCE AEROSOLS (TERESA): APPLICATION TO POWER PLANT-DERIVED $PM_{2.5}$

Semi-Annual Technical Progress Report

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Principal Author: Dr. Annette Rohr, EPRI

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Submitted by:
Electric Power Research Institute
3412 Hillview Ave.
Palo Alto, CA 94304

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ABSTRACT

This report documents progress made on the subject project during the period of March 1, 2006 through August 31, 2006. The TERESA Study is designed to investigate the role played by specific emissions sources and components in the induction of adverse health effects by examining the relative toxicity of coal combustion and mobile source (gasoline and/or diesel engine) emissions and their oxidative products. The study involves on-site sampling, dilution, and aging of coal combustion emissions at three coal-fired power plants, as well as mobile source emissions, followed by animal exposures incorporating a number of toxicological endpoints. The DOE-EPRI Cooperative Agreement (henceforth referred to as "the Agreement") for which this technical progress report has been prepared covers the performance and analysis of field experiments at the first TERESA plant, located in the Upper Midwest and henceforth referred to as Plant 0, and at two additional coal-fired power plants (Plants 1 and 2) utilizing different coal types and with different plant configurations.

During this reporting period, data processing and analyses were completed for exposure and toxicological data collected during the field campaign at Plant 1, located in the Southeast. Toxicological results indicate some pulmonary, oxidative stress, and cardiovascular responses to certain exposure scenarios.

Fieldwork at Plant 2, located in the Midwest, began on July 19, 2006. The following scenarios were completed:

- July 19-22: POS (oxidized + SOA)
- July 25-28: PONS (oxidized + neutralized + SOA)
- August 8-13: P (primary)
- August 14-15: POS
- August 16-17: POS (MI rats)
- August 28-31: OS (oxidized + SOA, without primary particles)
- September 1-4: O (oxidized, no primary particles)
- September 6-9: S (SOA, no primary particles)

During the next reporting period, we will report complete exposure and toxicological results for Plant 2. Planning will begin for the mobile source component of the research (funded through the Harvard-EPA Center for PM Health Effects), scheduled to take place in 2008. We will also hold our annual meeting of the TERESA Technical Advisory Committee, planned for early in 2007.

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1.0 INTRODUCTION

The TERESA study investigates the role played by specific emissions sources and components in the induction of adverse health effects by examining the relative toxicity of coal combustion and mobile source (gasoline and/or diesel engine) emissions and their oxidative products. The work is a significant improvement over previous studies to investigate the toxicity of coal combustion-derived particulate matter by virtue of several highly innovative and unique design features. First, all toxicological studies of coal combustion emissions to date (some of which have shown biological effects) have used primary emissions, ie. coal fly ash (e.g. MacFarland *et al*., 1971; Alarie *et al.*, 1975; Raabe *et al*., 1982; Schreider *et al.*, 1985). The relevance of primary emissions to human population exposure is unclear, since primary PM emissions are now very low with the widespread introduction of particulate controls on power plants. It is the secondary particulate matter formed from SO_2 and NO_x in stack emissions as well as any residual primary PM that is of interest. No efforts to consider and account for secondary atmospheric chemistry have been made to date. By examining aged, atmospherically transformed aerosol derived from stack emissions, TERESA will enable the determination of the toxicity of emissions sources in a manner that more accurately reflects the exposure of concern. In addition, the atmospheric simulation component of the project will allow the investigation of the effect of different atmospheric conditions on the formation and toxicity of secondary PM. Second, the primary PM used in the studies to date has typically been generated through the use of pilot combustors in a laboratory setting. There is concern that pilot combustors may not accurately mimic stack emissions due to differences in surface to volume ratios and thus time-temperature histories. The fact that TERESA involves assessment of actual plant emissions in a field setting is an important strength of the study, since it directly addresses the question of representativeness of emissions.

The study involves on-site sampling and dilution of coal combustion emissions at three coal-fired power plants, as well as mobile source emissions. Emissions are introduced into a reaction chamber to simulate oxidative atmospheric chemistry, and both primary and secondary materials are extensively characterized, including NO_2, SO_2, ozone, NH_3, hydrocarbons, particle number and mass (including ultrafines), sulfate, nitrate, elemental/organic carbon (EC/OC), ammonium, and metals. Test atmospheres containing depleted emissions and emission oxidative products are utilized in two toxicological assessment steps, the first utilizing normal laboratory rats, and the second consisting of a comprehensive toxicological evaluation in a rat model of susceptible individuals. This last step includes telemetric methods for the assessment of cardiac function.

The primary objective of the project is to evaluate the potential for adverse health effects from ambient exposure to realistic coal-fired power plant emissions. Secondary objectives of the study are to: (1) evaluate the relative toxicity of coal combustion emissions and mobile source emissions, their secondary products, and ambient particles; (2) provide insight into the effects of atmospheric conditions on the formation and toxicity of secondary particles from coal combustion and mobile source emissions through the simulation of multiple atmospheric conditions; (3) provide information on the impact of coal type and pollution control technologies on emissions toxicity; and (4) provide insight into toxicological mechanisms of PM-induced effects, particularly as they relate to susceptible subpopulations. The study findings will help to answer questions regarding which constituents of PM are responsible for the negative health outcomes observed, the likely sources of these constituents, and the degree to which further regulation of PM will improve human health.

The DOE-EPRI Cooperative Agreement for which this technical progress report has been prepared involves the analysis and interpretation of the field data collected at the first power plant (henceforth referred to as Plant 0, located in the Upper Midwest), followed by the performance and analysis of similar field experiments at two additional coal-fired power plants (Plants 1 and 2) utilizing different coal types and with different plant configurations. The Agreement also includes a comparison of the toxicity of coal power plant emissions, mobile source emissions and concentrated ambient particles (CAPs). Animal exposure experiments to evaluate the toxicity of mobile source emissions and CAPs are also part of the overall TERESA program, but will be performed by the project team independently of the Agreement.

2.0 EXECUTIVE SUMMARY

Activities conducted during this reporting period (March 1, 2006 through August 31, 2006) focused on completing data analysis and processing for exposure characterization and toxicological data collected during Plant 1 fieldwork, and on initiating exposures at Plant 2.

To recap, seven sets of animal exposures were carried out at Plant 1. Normal rats were exposed to four different scenarios (with one repeated), while MI (compromised) rats were exposed to one scenario, which was conducted in replicate. The *in vivo* chemiluminescence (CL) data suggest that both lung and heart oxidative stress occur in response to several scenarios; in addition, some subtle pulmonary effects were observed. Stage II assessments conducted at Plant 1 suggested no apparent effect of any of the scenarios on heart rate or on several measures of heart rate variability. However, the PONS scenario resulted in an increase in cardiac arrhythmias (premature ventricular beats; PVBs) in exposed animals compared to sham/control animals.

Fieldwork at Plant 2, located in the Midwest, was initiated on July 19, 2006. The following scenarios were completed:

- July 19-22: POS (oxidized + SOA)
- July 25-28: PONS (oxidized + neutralized + SOA)
- August 8-13: P (primary)
- August 14-15: POS
- August 16-17: POS (MI rats)
- August 28-31: OS (oxidized + SOA, without primary particles)
- September 1-4: O (oxidized, no primary particles)
- September 6-9: S (SOA, no primary particles)

A small subset of exposure data were available at the time of submission of this progress report. The remainder of the exposure data, and the toxicological data, are being analyzed and will be reported in the next progress report.

Overall progress on the Project tasks is shown in the Table below. Note that the scheduled completion date for the Project has been extended due to a number of technical delays. We now anticipate completion of the project by December 31, 2008.

Technical Progress - 34 months

Task #	Description	Planned % completed	Actual % completed
1	Complete Study at Upper Midwest Power Plant	100%	100%
2	Field Study at Power Plant #1	100%	100%
3	Field Study at Power Plant #2	100%	75%
4	Relative Toxicity of Coal Plant Emissions, Mobile Sources, and CAPs	100%	0%
5	Preparation of Peer-Reviewed Journal Articles	100%	40%
6	Project management and reporting	100%	55%

Priorities for the next reporting period (September 1, 2006 – February 28, 2006) include:

- Finalization of a draft topical report for the Plant 0 findings
- Finalization of a draft topical report for the Plant 1 findings
- Completion of laboratory and toxicological analyses for Plant 2

3.0 EXPERIMENTAL

A detailed description of the experimental setup and methods development is not provided in this report as these topics were covered extensively in prior semiannual reports.

4.0 RESULTS AND DISCUSSION

4.1 Stack Gas Sampling

The stack gas at Plant 2 had a temperature of only about 50 C, compared to about 140C at the Plants 0 and 1. In addition, the gas was saturated with water, and there was additional water mist. Initial tests showed that the sampling probe used for the first two plants could not be used at Plant 2 because the mist deposited on the walls and trapped a large fraction of the particles. To overcome this problem, a new sampling probe was developed. Hot, dry, clean air was mixed with stack gas at the inlet to the probe, preventing water deposition on the surfaces, and the mixture was then transported through a long narrow tube to control the flow into the aspirator (the same as used in the original probe). The diagram for the probe was not available at the time of submission of this report. This novel probe also has the promise of making it much easier to perform simple routine monitoring of stack gas particles, for both integrated and continuous measurements.

4.2 Exposure Characterization

Because the APS instrument used for continuous monitoring of coarse particles at Plants 0 and 1 malfunctioned, a DustTrak continuous aerosol instrument was used to monitor the particle concentration in the reaction chamber. While the DustTrak does not provide either size distribution or a direct measurement of mass concentration, since it uses light scattering, it is quite adequate for the purpose of showing that a stable amount of secondary particles are being created in the reaction chamber. The actual mean mass concentration is subsequently determined by gravimetric analysis for integrated particle samples collected on Teflon filters, which then allows normalization of the DustTrak data to provide a good estimate of actual mass vs time. Also, because we could no longer measure the size distribution of larger particles with the APS, and since the fraction of secondary particles with size < 0.5 μm (measured at Plants 0 and 1 using an SMPS) was quite small, we decided that it was not necessary to use the SMPS at Plant 2 to measure particles produced in the reaction chamber. Since space inside the mobile reaction laboratory is extremely limited, the substitution of the DustTrak for the combined APS/SMPS has made it a little easier for the field staff to work in the laboratory.

The TEOM used to measure continuous particle mass concentration of the exposure atmosphere also malfunctioned. While we had the option of repairing this instrument, there have been numerous problems during transport of this instrument back and forth from the manufacturer, due to the fragile nature of its construction. So we decided to use a second DustTrak to continuously monitor the particle mass concentration for the exposures.

Table 1 summarizes the scenarios carried out at Plant 2. Exposure data available at the time of preparation of this report are shown in Table 2. Integrated measurements for chemical species, such as metals, EC/OC, ions, etc, will be analyzed together after the completion of fieldwork.

Table 1. Summary of Plant 2 exposures and experiments.

Round	Code	Scenario	Dates	Animal Model
1	POS	Oxidized + SOA	July 19-22	Normal
2	PONS	Oxidized + Neutralized + SOA	July 25-28	Normal
3	P	Primary	August 8-13	Normal
4	POS	Oxidized + SOA	August 14-15	Normal
5	POS	Oxidized + SOA	August 16-17	MI Model
6	OS	Oxidized + SOA (no primary particles)	August 28-31	Normal
7	O	Oxidized (no primary particles)	September 1-4	Normal
8	S	SOA (no primary particles)	September 6-9	Normal

Table 2. Continuous measurements during experimental runs at Plant 2, July-September, 2006.

Exposure Parameter	Round 1 (POS)	Round 2 (PONS)	Round 3 (P)	Round 4 (POS)	Round 5 (POS)	Round 6 (OS)	Round 7 (O)	Round 8 (S)
Temperature(˚C)	23.0±0.9	21.9±0.3	23.3±1.0	24.6±1.2	24.5±0.5	24.5±1.5	23.5±0.0	23.9±0.3
RH (%)	66.6±12.0	53.0±17.1	56.1±17.6	48.6±17.7	31.4±15.6	47.5±10.2	38.7±10.3	36.0±2.0
O_3 (ppb)	24.1±11.9	15.2±6.6	8.9±3.3	31.5±5.4	37.0±3.8	19.9±3.3	18.3±4.2	21.0±2.4
NO (ppb)	6.7±0.8	6.3±0.3	7.5±2.4	7.3±1.7	8.1±2.7	7.5±3.8	5.8±0.1	8.4±0.7
NO_2 (ppb)	5.5±0.3	3.7±2.2	4.4±0.8	3.5±1.2	4.5±1.8	2.0±0.4	2.5±0.7	3.8±1.0
SO_2 (ppb)	111.9±109.5[a]	23.1±6.9	38.9±15.7	25.7±1.4	41.6±4.2	15.1±6.6	33.9±16.4	27.3±9.8
PM Count (cm^{-3})	38,400±5,386	38,483±3,651	55,947±11,769	42,867±1,656	42,116±13,653	35,959±6,290	29,294±2,392	7,574±1,598
Gravimetric Mass ($\mu g\ m^{-3}$)[b]	279.0±64.7	244.4±10.2	NA[c]	NA	NA	NA	NA	NA

Notes. [a] The mean value contains an extremely high SO_2 episode, attributed to a brief scrubber problem; [b] Integrated mass concentration; [c] Not available. Rounds 1-3 and 6-8 were four days in duration; Rounds 4 and 5 were two days in duration. Values expressed as mean ± sd.

4.3 Toxicological Assessments

Toxicological data for Plant 2 were not available at the time of submission of this report. These data will be documented in the next semiannual report.

5.0 CONCLUSIONS

Significant progress was made on the Project during this reporting period. We completed fieldwork at Plant 2, and laboratory and data analyses are underway.

Priorities for the next reporting period (September 1, 2006 – February 28, 2007) include:

- As required under the Cooperative Agreement, finalization of the draft topical report for the Plant 0 findings.
- As required under the Cooperative Agreement, finalization of the draft topical report for the Plant 1 findings.
- Completion of laboratory and toxicological data analyses for Plant 2, located in the Midwest.