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Trip Report for the 2005 Sino-American SF₆ Tracer Experiment

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Executive Summary

The Chinese Institute for Radiation Protection (CIRP) conducted an SF₆ atmospheric tracer experiment in July 2005 in the vicinity of the Qinshan Nuclear Power Company complex on the coast of the East China Sea. The experiment was partially sponsored by the US Department of Energy National Nuclear Security Administration, under the NA-23 International Emergency Management and Cooperation Program. NA-23 sent a delegation of five scientists to observe the experiment; four of the observers were from Lawrence Livermore National Laboratory (LLNL) and one was from the Japan Atomic Energy Research Institute (JAERI). CIRP's cooperation with the US-Japanese delegation was excellent, and the project was very successful from the international cooperation perspective. Although the experiment was modest in scope, it may provide one or more data sets that can be used for international dispersion model validation and intercomparison projects. Several areas for procedural improvements were noted by the US and Japanese observers, and a more concise measure of the experiment's scientific value will be available after CIRP completes and delivers the database of the experiment results by the end of the fiscal year. The consensus recommendation of the observers is that CIRP and DOE/NNSA NA-23 build on the experience and personal contacts gained during the experiment to plan and conduct an even more effective experiment in the future, perhaps as early as next year (2006). If the decision is made to conduct a follow-on experiment, we strongly recommend that the LLNL and JAERI representatives work cooperatively with CIRP throughout the entire planning phase of the experiment. As discussed in Section V, a 2006 China tracer experiment could serve as a springboard to a 2007 long-range international tracer experiment involving South Korea.

I. Introduction

Lawrence Livermore National Laboratory scientists Michael Bradley, Garrett Keating, Marty Leach, and Tom Sullivan traveled to Haiyan (120 km southwest of Shanghai), Zhejiang Province, People's Republic of China during the period of 13 – 20 July 2005 (13 – 19 July for Sullivan) to observe an atmospheric tracer experiment conducted by the China Institute for Radiation Protection in the vicinity of the Qinshan Nuclear Power Company (QNPC) complex. The experiment was partially sponsored by DOE/NNSA NA-23. The four-person LLNL team provided a well balanced cross section of scientific, technical, and project management expertise to observe and evaluate the experiment. Dr. Masamichi Chino of JAERI accompanied the LLNL scientists (under the sponsorship of DOE/NNSA NA-23). Dr. Chino provided additional depth and an international scope to the observing delegation.

The general purpose of the experiment was to develop a database of atmospheric dispersion characteristics in the vicinity of the QNPC complex by releasing and tracking a benign tracer gas (sulfur hexafluoride, SF₆) on days when prescribed, climatologically typical atmospheric conditions existed. The experiment plan called for 10-15 separate SF₆ releases during the time

period of 28 June – 20 July 2005. It is hoped that the resulting database will be adequate to support validation studies of several countries' atmospheric dispersion models.

The LLNL team's key contacts in China were: Professor Xuan Yiren (CIRP Director-General), Professor Hu Erbang (CIRP), Niu Yujuan (Deputy Director, General Office, CIRP), Yan Jiangyu (CIRP), Cheng Wei (CIRP translator), Professor Wu Meijing (Assistant General Manager, QNPC), Xu Dongwu (Deputy Manager, Environment and Emergency Division, QNPC), and Zhang Zai Cheng (Headmaster, Haiyan Senior High School). One highlight of the trip was the opportunity for the LLNL scientists to work with 42 students from Haiyan Senior High School (see Figures 1 and 2). These highly motivated, eager, and bright high school students were the participants in the 2005 Sino-American Qinshan Nuclear Power Corporation SF₆ Science Summer Camp.

II. Overview of Experiment Procedure

The SF₆ was released from a tower (Figure 3) near the QNPC complex and air samples were collected (Figure 4) at predetermined sampling locations on five approximately concentric arcs downwind from the release point. The air samples were then analyzed for SF₆ concentration using gas chromatography (Figures 5 and 6).

The geographical configuration of the air sampling network was based on surface- and tower-observed winds for June and July during the three-year period of 2000-2002. During those three years, the prevailing winds in the vicinity of QNPC at 10 meters above ground level were from the direction sector ranging from east-southeast to east, and the prevailing winds at 63 meters above ground level were from the direction sector ranging from south-southeast to east-southeast. The air sampling sites were selected based on this three-year climatology, and the fact that the SF₆ was released from a tower at the 30-meter level. The sampling sites were located on each of five approximately concentric arcs centered about a line extending west-northwest from the release point. As discussed in the Section III, the actual wind direction during the experiment often did not correspond to the three-year climatological mean.

During the field experiment, meteorological observations were collected from 13 locations, including five or six towers in the local area (two of which were located at Qinshan Nuclear Power Plants I and II). The tower observations were taken at three height levels (10m, 30m, and 63m). Weather balloons were launched to measure winds aloft when permission was granted by the nearby Chinese Air Force Base. Unfortunately, due to frequent flight operations, weather balloons were not allowed to be launched coincident with any of the actual SF₆ releases. (In fact, during one tracer release event, the Chinese Air Force was dropping exploding training bombs within approximately 200 yards of one the air sample collection sites.)

The general sequence of events for an experiment day began on the previous day with a review of the forecasted weather conditions for the experiment day. On each experiment day, before each tracer release, Professor Hu and his associates used computer displays at the QNPC emergency operations center to analyze real-time meteorological observations from the towers and three of the surface stations in the area to determine if the wind direction would be adequate to transport all, or at least most of, the tracer plume over the arcs of the air sampling network. If

it appeared that the wind direction was appropriate for a tracer release, Professor Hu specified the release time, estimated the most likely air sampling sites to be under the plume for each of the five arcs, and deployed the high school students on buses to those specific sampling sites. Starting at the prescribed time, the SF₆ was released for a one-hour period from the tower, and the high school students collected air samples at their assigned sites, using 10-minute sampling periods and a sampling schedule provided by Professor Hu. At the end of each release and sample collection sequence, the air samples were returned to the high school where a CIRP scientist analyzed their SF₆ concentrations.

CIRP will consolidate the weather observations and SF₆ concentration measurements into a database, which will be delivered to LLNL by the end of FY2005. If of sufficient quality, this database will be used to validate atmospheric dispersion models from several countries, including the US (NARAC), China (CIRP), and Japan (JAERI).

III. Summary of Activities during the Experiment

Professor Hu arrived in Haiyan on June 27 and began preparing for the tracer releases. On July 2 and 3 he selected appropriate specific sampling sites on the five arcs described above. He began training the students on July 3 and took them on a familiarization tour of the sampling sites on July 4. On July 5 the location of each sampling site was mapped using GPS.

On July 6 all preparations were completed and the team was ready to begin the experiment but, unfortunately, the wind direction during the first portion of the experiment period was not what had been anticipated based on the three-year climatology. The first attempt of an SF₆ tracer release occurred on July 6, but the release had to be cancelled because the wind would not have carried the SF₆ over the sampling network. Two releases were successfully conducted on July 7. Then rain prevented the team from conducting a release on July 8, and in the following days, inappropriate wind directions and additional rain prevented the team from conducting further releases.

The US-Japan delegation arrived in Haiyan on Thursday, July 14. On the morning of July 15 the members of the delegation were introduced to the scientific summer camp students and worked with them in the classroom. In the afternoon we visited the Qinshan nuclear power plant complex and had a planning meeting with Professor Hu. Based on forecast information that was available that afternoon (July 15), it appeared that on the next day the wind direction might be appropriate for a tracer release. It turned out that we were able to conduct three tracer releases on Saturday, July 16. That evening we once again reviewed the weather data and forecast information, and decided that the approach of Typhoon Haitang would cause the wind direction to be favorable on the next day. On Sunday, July 17 we were able to conduct two more tracer releases, even though the winds were relatively strong and the predicted plume path was not expected to completely overlap the air sampling grid. The weather in the following days was not appropriate for further releases, but we were quite pleased that, despite the atypical weather conditions, we were able to conduct a total of seven tracer releases.

IV. Comments on Experimental Procedures

The release and sampling strategy were not quite consistent. The SF₆ release was for 1 hour, with sampling for two, ten-minute periods in the middle of the 1-hour period. The 1-hour period for each station was calculated from a transit time estimated from the mean wind. This method does not account for any local or mesoscale wind variations. Even with steady winds, it is hard to justify continuing the release after sampling has ceased. This can be important because several releases were done in the same day, and it is essential that the tracer plume from one release clears the test area before the next release begins. It is not clear that adequate time was allowed for this to occur.

The SF₆ was released from a tower at about 30m above ground level to simulate the expected release height of an effluent from the power plants. The release was done manually with the SF₆ tank raised to that level on the tower. The only control on the release rate was the operator controlling the release to compensate for condensation on the valve (condensation on the valve changed the release rate). The amount released was calculated by weighing the tank before and after the release.

The design of the arcs at fixed distances from the release point was similar to what is often done in dispersion experiments here and in other countries. Centerline concentration is an often used diagnostic for dispersion modelers. The reality that the arcs are not perfect is part of doing field work. The modelers and analysts using the data are adept at correcting for irregular angles and distances.

There are several suggestions for future experiments that could make the data more useful. These are relatively inexpensive modifications and could be implemented without a lot of additional manpower. First is making the release and sampling strategy consistent with each other. There are several options that could be talked through in a design conference call or meeting. One example that we would advocate is for all samplers to begin at the same time, the time of the release. The near field arcs could sample for shorter intervals or sample with less bags. There is no reason to limit each site to two bags. The transit time to the farthest sampling site on each arc would determine when to stop sampling, but only after an adequate interval after that longest transit time. The idea is to sample all of the SF₆ released.

A flow meter on the tracer release tank should also be utilized and recorded. Weighing the tank before and after release is a good quality check on the amount released. If condensation is a problem, simple heating methods to prevent that could be utilized.

It appears that the experiment was designed by a single person, Professor Hu, with very little cross-checking or exploration of his ideas. He put together a reasonable experiment with his limited resources and knowledge of other similar experiments. A few days of planning and a better laid-out experimental plan would result in a much more useful experiment.

The field measurement component of the study was very rudimentary. Field measurement commenced with the communication of what appeared to be plume transit time (in minutes) from the Emergency Center to a field coordinator who mentally converted it to clock time for the

collection of samples at the 40+ sample locations. This information was manually recorded on paper that was provided to a high school student who then assigned students to specific sampling locations which required additional transcription of the sampling times. Students labeled each of two sampling bags with test number, sample location, and sample sequence prior to sample collection. Of the four students observed, two committed errors with this protocol, one failing to record the bag sequence and the other failing to note a delayed start of sampling due to equipment malfunction. Once the tests were completed, students returned the samples to the transport vehicle with no record of receipt or cross-check of their labeling accuracy. Upon return to the field center, samples were transported to the laboratory for analysis and analyzed immediately according to study staff. The sampling bags used do not appear to be analytical-grade. No samples for detection of background levels of SF₆ were obtained. Maintenance and calibration of sample pumps were not determined from the field coordinator.

The analytical equipment used for the study was acceptable, although determination of the quality of the data obtained was not feasible due to time and language constraints. The analysis laboratory was operated in a high school laboratory classroom without a fume hood or other standard laboratory equipment (such as an eye wash or compressed gas lines). The gas chromatograph was a Perkin Elmer Auto System XL gas chromatograph with Windows-based chromatography software (specific software unidentifiable). Sample analysis consisted of an analyst selecting a sample from a large group of sampling bags, obtaining a 100- μ l sample from the bag by 1-mL syringe and injecting the sample into the gas chromatograph. A second analyst recorded the sample identification by hand in a log book and the corresponding peak height for SF₆ from the chromatogram. It appeared that samples were injected serially in the same data file so that a data file consisted of a long chromatogram with multiple samples contained within the single chromatogram. Peak height and area were determined by the chromatography software. The use of a liquid-handling syringe as opposed to a gas-tight syringe and the lack of SF₆ background samples are potential sources of error in the analysis.

Analytical calibration was conducted by injecting quantities of SF₆ into 100-mL glass syringes, waiting sufficient time for equilibration, and then injecting samples from the syringe into the gas chromatograph. Five calibration standards ranging from 10⁻⁷ to 10⁻¹¹ were analyzed this way and a calibration coefficient of 0.999 was obtained, according to the recording analyst. Sample values not falling within the calibration range were estimated with a linear equation obtained from fitting the calibration results. The frequency of calibration was not determined from the analysts. This method for preparing calibration standards is not a recognized volumetric method for preparing and maintaining calibration standards. The nature of a quality assurance/quality control program was not determined from the analysts.

As with the field measurement component, the meteorological tools for pre-experiment planning and real-time operational decision making also were rudimentary. The three-year local climatology was inadequate for selecting the experiment dates and for choosing the air sampling site locations. Although unusually warm water temperatures in the East China Sea may have suppressed a more typical sea breeze circulation, a 10- or 20-year climatology would have provided much better insight for the experiment planning process. Even though the QNPC Emergency Operations Center was used as the experiment operations control point, the available meteorological information consisted of only the current wind vectors from three surface stations

and five or six meteorological towers. No time history or graphical analysis of the local meteorological data was available, nor were any larger-geographical-scale meteorological products available to provide the decision makers with the bigger meteorological picture (essential for anticipating changes in weather conditions). Furthermore, no plume modeling tools, such as QNPC's Gaussian emergency response model or CIRP's TW-NAOCAS model (which runs on a laptop computer), were employed to help estimate plume paths and select the most probable sample sites. The use of these models could have minimized the subjectivity of the release time selection process and the plume trajectory estimation process, and would have reduced the stress on the project director. The unavailability of wind profile data from local weather balloons due to conflicts with nearby military aircraft flight operations caused serious data voids in the geographical domain to be simulated in future model comparison studies. Perhaps the only solution to this problem is to conduct future experiments at a different location.

V. Recommendations

A. The consensus recommendation of our team is that CIRP and DOE/NNSA NA-23 build on the experience and personal contacts gained during this experiment by cooperatively planning and conducting an even better experiment in the future, perhaps as early as next year. If the decision is made to conduct a follow-on experiment, we strongly recommend that the LLNL and JAERI representatives work cooperatively with CIRP throughout the entire planning phase of the experiment, and that the lessons learned from the 2005 Sino-US SF₆ Tracer Experiment are adequately addressed during the planning of the next experiment.

B. During our time together in China, Dr. Masamichi Chino of JAERI suggested that we consider the possibility of a collaborative, international long-range tracer experiment over eastern Asia, covering China, Korea, and Japan. He suggested that a tracer release from Korea could be accomplished in association with the exchange of real-time predictions by emergency response systems during the next IAEA CONVEX 3 large-scale joint international command post exercise. Dr. Chino mentioned that in past short-range experiments, JAERI has always collaborated with the Japan Weather Association (JWA). He indicated that JWA has substantial experience with tracer experiments, and that JWA has samplers, atomizers, and gas chromatography capabilities for PFT tracer gas that is used for long-range experiments. Particularly considering the current situation with North Korea and the 2008 Olympics in South Korea, Dr. Chino's idea deserves serious consideration. One possible course of action might be to conduct a second tracer experiment in China in 2006 and invite the South Koreans to participate. The 2006 experiment could serve as the springboard for a 2007 or 2008 international tracer experiment such as suggested by Dr. Chino. A 2007 large-scale tracer experiment could provide a realistic database for the 2008 CONVEX 3 exercise.

C. Assuming that the Qinshan experiment database is available from CIRP by the target date of 30 September 2005, and that the data are of sufficient quality to be used for atmospheric dispersion model intercomparison studies, we suggest that LLNL host a workshop in early 2006 for representatives from CIRP, JAERI, and perhaps South Korea. The workshop participants would present, compare, and discuss their model simulations of the Qinshan tracer releases. If NA-23 concurs with recommendations A and/or B, the participants also could begin planning the second regional Chinese tracer experiment and the long-range international tracer experiment.

VI. Photographs



Fig 1. Haiyan Senior High School with welcoming sign for 2005 Sino-U.S. Joint SF₆ Tracer Experiment.



Fig. 2 SF₆ Science Summer Camp Students in classroom.



Fig. 3. Release of SF₆ from tower.
Note man on tower controlling release valve.



Fig. 4. Student collecting air sample with (left to right) Professor Xuan Yiren (CIRP Director-General), and Drs. Mike Bradley, Tom Sullivan, and Marty Leach (LLNL).



Fig. 5. Air samples ready to be analyzed in laboratory at the high school.

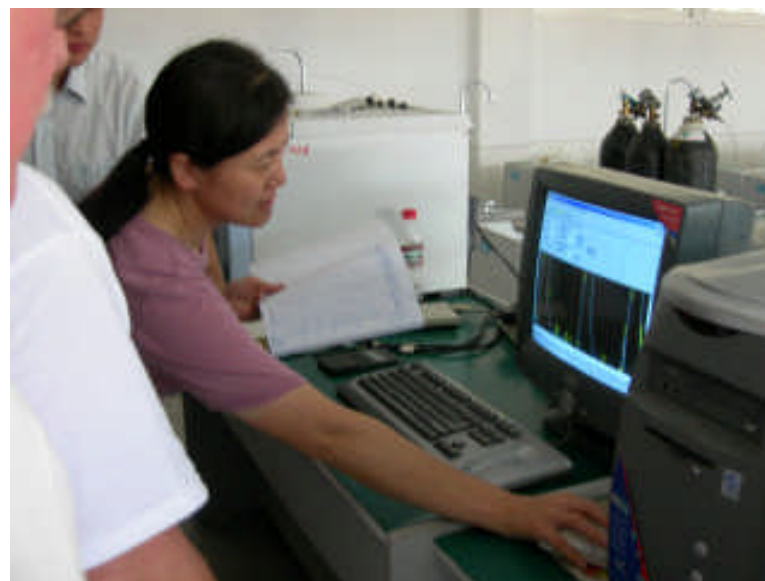


Fig 6. Gas chromatography analysis of air samples.