LESSONS LEARNED IN AEROSOL MONITORING WITH THE RASA

Joel B. Forrester[1], Ted W. Bowyer[1], Fitz F. Carty[2], Laura Comes[2], Paul W. Eslinger[1], Larry R. Greenwood[1], Derek A. Haas[1], James C. Hayes[1], Randy R. Kirkham[1], Elwood A. Lepel[1], Kevin E. Litke[1], Harry S. Miley[1], Scott J. Morris[1], Brian T. Schrom[1], Peter Van Davelaar[2], and Vincent T. Woods[1]

Pacific Northwest National Laboratory[1] and General Dynamics[2]

Sponsored by the United States Army Space and Missile Defense Command

Award Nos. MIPR0FO89TGASF[1] and W9113M-08-C-0173[2]

ABSTRACT

The Radionuclide Aerosol Sampler/Analyzer (RASA) is an automated aerosol collection and analysis system designed by Pacific Northwest National Laboratory (PNNL) in the 1990s and is deployed in several locations around the world as part of the International Monitoring System (IMS) required under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The RASA operates unattended, save for regularly scheduled maintenance, iterating samples through a three-step process on a 24-hour interval. In its 15-year history, much has been learned from the operation and maintenance of the RASA that can benefit engineering updates or future aerosol systems.

On 11 March 2011, a 9.0 magnitude earthquake and tsunami rocked the eastern coast of Japan, resulting in power loss and cooling failures at the Daiichi nuclear power plants in Fukushima Prefecture. Aerosol collections were conducted with the RASA in Richland, WA. We present a summary of the lessons learned over the history of the RASA, including lessons taken from the Fukushima incident, regarding the RASA IMS stations operated by the United States.

OBJECTIVES

The Radionuclide Aerosol Sampler/Analyzer (RASA) is an automated aerosol collection and analysis system designed by Pacific Northwest National Laboratory (PNNL) in the 1990s, described in Miley et al. (1998), Bowyer et al. (1997), and McKinnon et al. (1998), and is deployed in several locations around the world in support of the International Monitoring System (IMS) specified in the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The RASA operates unattended, save for regularly scheduled maintenance, iterating samples through a three-step process on a 24-hour interval. The basic layout of the RASA collection and detection scheme is shown in Figure 1.
In its 15-year history, much has been learned from the operation and maintenance of the RASA that can benefit engineering updates or future aerosol systems.

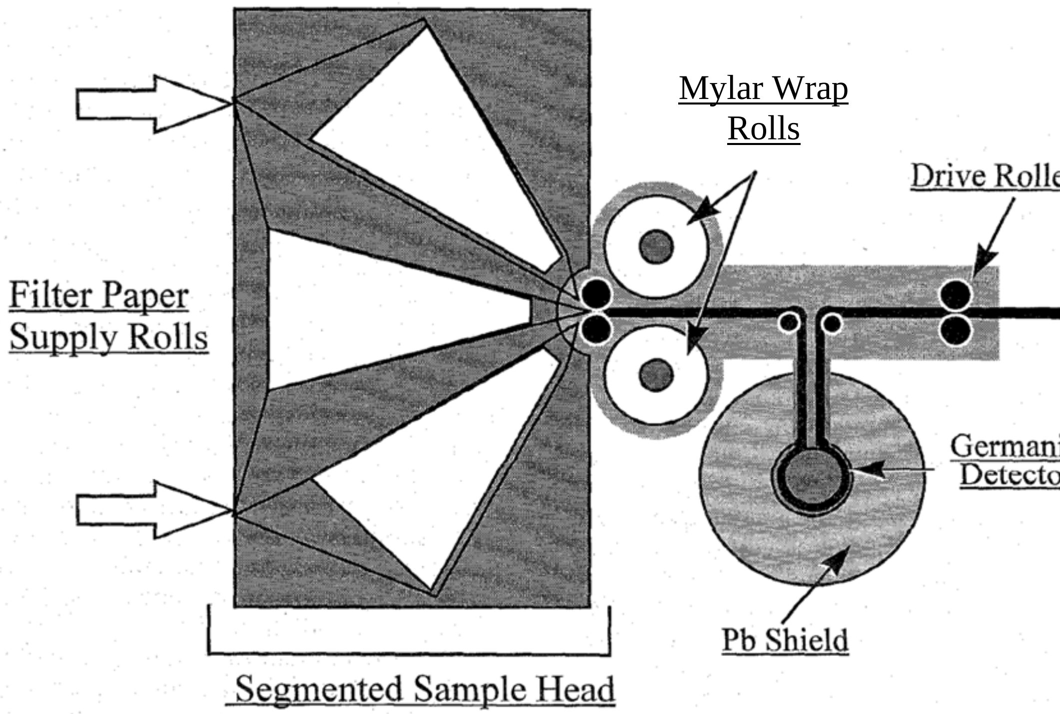

Figure 1. Schematic of the collection filter path in the RASA.

General Dynamics (GD) acts as the equipment provider and oversees the operations and maintenance (O&M) responsibilities for the eleven IMS radionuclide stations owned and maintained by the United States. As such, GD is in a unique position to gather and evaluate performance data and assess the operational impact of both equipment and O&M issues and anomalous events.

On 11 March 2011, a 9.0 magnitude earthquake and tsunami rocked the eastern coast of Japan, resulting in power loss and cooling failures at the Daiichi nuclear power plants in Fukushima Prefecture. In addition to all eleven of the U.S. IMS RASAs being fully operational during the Fukushima event, some non-U.S. RASAs successfully collected and measured aerosols. Additional aerosol collections were conducted with a non-networked RASA in Richland, WA.

RESEARCH ACCOMPLISHED

Over several years of maintaining the network of U.S. RASA stations shown in Figure 2, GD has logged the most common modes of failure affecting the individual RASA subsystems and components. The locations of the eleven U.S. RASA stations are listed in Table 1.

Many of the radionuclide (RN) IMS stations employ mechanical coolers to maintain the low temperature needed for the operation and excellent sensitivity of high purity germanium (HPGe) detectors, especially in remote locations and sites at which regular commercial liquid nitrogen is not available or cost prohibitive. Failures related to the mechanical coolers comprise a significant portion of missing IMS data availability for aerosol systems. Previous work has gathered data to support investigations leading to adoption of new cooler technology. Past, current and R&D systems are considered.

Figure 2. The eleven RASA stations maintained by the United States (RN70–RN80).

Table 1. U.S. RASA station designations and locations

Station	City/Location	Territory
RN70	Sacramento	California
RN71	Sand Point	Alaska
RN72	Melbourne	Florida
RN73	Palmer Station	Antarctica
RN74	Ashland	Kansas
RN75	Charlottesville	Virginia
RN76	Salchaket	Alaska
RN77	Wake Island	
RN78	Midway Islands	
RN79	Oahu	Hawaii
RN80	Upi	Guam

General Dynamics, in concert with the Provisional Technical Secretariat (PTS) of the Comprehensive Nuclear-Test-Ban Treaty Organization, has accumulated >46 instrument years (~ 6 calendar years) of operating experience with the X-Cooler models produced by ORTEC. A significant number of spontaneous temperature excursions were observed among the IMS RASA stations. The state-of-health (SOH) data from the RN stations were examined with particular emphasis on the detector crystal temperature.

One especially troublesome observation is the spontaneous temperature excursion, i.e., warming, of the detector. A significant excursion is defined as a temperature increase of greater than 30 °C above the normal baseline temperature (typically -185 °C) that is not due to loss of cooler power. Of the eleven spontaneous temperature excursions recorded, none were related to power outage, vacuum problems, or other apparent problems and the effect to mission capability was no more than a few days.

Both GD and the PTS have aggressively pursued alternative cooling technologies to solve the frequent cooler failure and spontaneous detector warm-up problems. Recent work has been done to customize commercially available off-the-shelf electrical cooling options to the RASA as described in Yocum et al. (2008) and Yocum et al. (2010). One solution that has shown promising results in a non-RASA IMS RN station, as explained in Ezequiel et al. (2011), is the Cryo-Cycle, manufactured by Canberra Industries. The Cryo-Cycle couples a Stirling cooler with a liquid nitrogen (LN_2) Dewar, reliquifying the gaseous nitrogen to maintain a constant supply of liquid nitrogen. A manufacturer modification of the Cryo-Cycle designed to accommodate the RASA configuration is show in Figure 3.

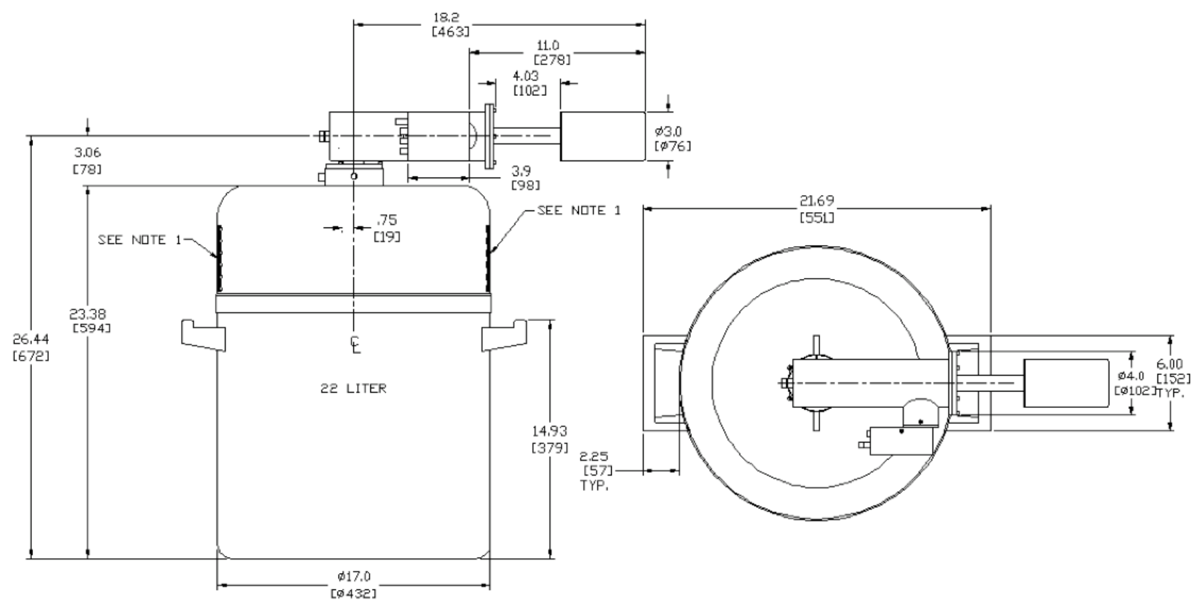

Figure 3. Canberra Cryo-Cycle configured for RASA (image courtesy of Canberra).

Another alternative to the standard electrical cooler being considered and evaluated by the PTS is a compact liquid nitrogen generator. PTS has identified the ELAN2 manufactured by MMR in California as their preferred model for testing and potential implementation. The ELAN2 is currently being tested at two RN stations, RN47 at Kaitaia, New Zealand and RN26 at Nadi, Fiji. Until very recently, the PTS was testing a third ELAN2 unit at their headquarters in Vienna. This unit (pictured in Figure 4) is currently slated for service by the manufacturer, after which it will be on loan to PNNL for testing, engineering modification for use with the RASA, and evaluation of new technical solutions for improvement.

Following the earthquake and tsunami near Fukushima Prefecture that resulted in power loss and cooling failures at the Daiichi nuclear power plants, the station operators of the Japanese RASA at Takasaki (RN38) reported useful lessons taken from the power outage as well as high activity seen inside the station and on the filter material in Kumata and Tomita (2011). The station operators elected to decrease the flow rate of their RASA to approx 300 m^3/hr in the days following the first observation of high-activity samples (approx 30% of normal operation). After power losses (reportedly >3 hr) the detector warmed up to -139 °C. Two electronic components failed to automatically restart after power restoration.

Figure 4. MMR ELAN2 in standard configuration (image courtesy of PTS).

CONCLUSIONS AND RECOMMENDATIONS

The lessons learned and recommendations for the RASA are several and broad. For clarity, the lessons and recommendations are divided into those based upon the long-term operation and maintenance of the RASA systems and those taken from the Fukushima event.

Long-Term Lessons and Recommendations

The serviceable lifetime and sustainability of system components is a currently relevant issue. The RASA was commercialized almost fifteen years ago. In the years since, no major design modifications or upgrades have been performed. The RASA has seen approximately twenty minor upgrades, more at the “tweak” level than component or subsystem redesign. The most common concerns regarding general system sustainability include obsolescence of original parts, availability of appropriate replacement parts, and reliability of detector cooling systems.

Electrical cooling of HPGe detectors remains the most significant and frequent cause of failure among the U.S. RASA systems. Several iterations of the ORTEC X-Cooler family have been tested and implemented, but the failure rate has remained excessively high. A viable long-term solution needs to be identified. Pursuant to this, GD, PTS, and PNNL are seeking cooling alternatives and testing currently available solutions. While LN_2 generators do look promising, reliance on a single cooling option has proved challenging in the past and as such other options must be evaluated, including the feasibility of using room-temperature detector options.

An obvious path toward long-term sustainability in the face of continued challenges with cooling of HPGe detectors is the consideration and evaluation of detectors that do not require external cooling. While HPGe is the gold standard for sensitive measurement and spectral analysis, the high fidelity comes at a high cost. Alternative detector materials, especially those capable of operating at room temperature, trade this convenience for decreased resolution. High purity germanium typically demonstrates a relative energy resolution of less than 1% (FWHM, 662 keV) while other typical non-cooled materials show resolution between 2%–3% (CdZnTe) and about 7% (NaI).

Additional upgrades considered important to long-term operation, sustainability, and logistics include the following:

- Solutions to mitigate electronic noise such as the use of shielded cable and the segregation of power and signal lines
- Hooks for expansion in the control software to allow alteration of sampling flow/time
- Predictive failure analysis algorithms could be used to pre-stage/pre-ship spares of parts/sensors likely to fail
- A second on-site detector (possibly more sensitive, more shielding, etc.) at remote sites to facilitate quicker confirmation analysis of interesting samples
- Lower power, higher efficiency collection means should be investigated and evaluated

Some upgrades or engineering changes worthy of consideration for impact to sampling handling issues include the following:

- Built-in filter splitting mechanism to avoid splitting/cutting samples, both in the field and at labs
- A mechanism to seal, cut, or possibly even compress individual samples in situ

Some of these upgrade solutions are currently being pursued and engineering designs being completed to include or address these issues. Given the historic challenges with spontaneous failures, commonly electrical coolers, the inclusion of additional state-of-health sensors into future RASA upgrade packages could provide valuable data about the condition and operation of components and subsystems in the time preceding failure. Other work at PNNL has shown the ability to develop predictive analytical tools, see Suarez et al. (2009), with the potential to predict the failure of components or sensors within a system.

Fukushima Lessons

There have been many lessons learned, including regarding calibration, procedures for high-level signals, and the need to have faster results. Most RASA-related lessons emerging from the Fukushima event are either a directly observed effect or based on the failure or lack of existing protocols and procedures.

Activity concentrations at some stations were measured above the level typically relevant for nuclear explosion monitoring and were seen to occasionally exceed the upper limits of the dynamic range of the measurement equipment. At such high concentration levels, radiation protection for health and safety of the operator and transport of samples becomes an issue. Radiation protection measures should be implemented at radionuclide station as standard operational procedures.

Take-away lessons from the Fukushima event include the potential need for internal contamination prevention measures, health physics concerns with respect to safety for the station operators and maintenance personnel, options to prevent the creation of very high activity samples, ways to make the measurement sooner (including mechanism for improving measurement in the presence of short-lived radon daughter isotopes, and mechanisms for recovery from power loss.

Specific measures to address these lessons may include the following:

- Contamination prevention, particularly for internal parts specific to sampling and counting activities, by such measures as dust mitigation changes or dust cover for filter rolls or by sealing, covering or otherwise protecting the detector and/or detector enclosure.
- Early response systems with real time measurements using low-resolution detectors (e.g., NaI, CsI) to assess high activity events and address safety concerns within the station as well as provide capability to modify sampling parameters in a high activity event, such as automatically decreasing the flow rate or decreasing the collection time. The high activity samples seen at RN38 after Fukushima suggest the need for a sort of “emergency situation” software script or state that would minimize the per-sample activity collected during

emergencies to maintain safe and transportable activity levels.

- Detector design changes so as to measure and screen short-lived isotopes (including singles and coincidence). Some detector configurations are being considered that would increase sensitivity to temporally-subsequent events while eliminating need for the current 24-hour decay period.
- Improved mechanisms for recovery from power loss

Areas for improvement also exist at the organizational level. Station operator manuals and guidelines need to be updated to reflect required or suggested actions following unusual power loss, unusually high radioactivity collections, and other off-normal events. In other words, the PTS should collaborate with experienced station operators, the equipment provider, and other relevant parties to produce a more comprehensive troubleshooting guide. Additionally, the Fukushima event has brought attention to the need for alternative operational guidelines and procedures for emergencies.

In addition to station-specific clarification and supplement, the PTS should consider enhancing or improving system-wide guidelines for such activities as handling and shipping of more highly radioactive samples, lab procedures to deal with such high activity samples (e.g., how to bring the sample into the lab for measurement, handling procedures within the lab, and storage and archiving of such samples). For example, at some IMS stations, the activity of RASA samples was feared to be too high for the station operator to be comfortable cutting for shipping and analysis. The U.S. IMS station operators are fortunate to have experts easily accessible to evaluate unusual situations and provide specific, appropriate guidance to enable the operators to handle and process samples and situations. A formalized guidance for all operators would greatly benefit the IMS.

As the operational lifetime of the RASA lengthens, at some point all concerned parties need to weigh the cost of continued obsolescence management and upgrades through component-level replacement against the benefit of or need for a newly-engineered system. The PTS has recently established a technology foresight website for relevant parties, but a more in-depth technical review and development forum should be set up to facilitate discussion between station operators, maintenance and logistics contractors, PTS, national laboratories, etc., regarding priorities for upgrades and promising future technologies.

ACKNOWLEDGEMENTS

The authors would like to thank the careful and regular effort of those local contractors that service the RASAs for the United States and who worked diligently to collect relevant data during the weeks following the earthquake and tsunami that impacted Japan. We also express deep gratitude to the RASA station operators in Japan, particularly Masahiro Kumata and Yutaka Tomita of the Japan Atomic Energy Agency, who collected vital early data and reported important lessons in the immediate wake of the natural disaster.

REFERENCES

Bowyer, S. M., H. S. Miley, R. C. Thompson, and C. W. Hubbard (1997). Automated particulate sampler for Comprehensive Test Ban Treaty verification (the DOE Radionuclide Aerosol Sampler/Analyzer), *IEEE Trans. Nuc. Sci.* 44:3, 551–556.

Ezequiel, A., F. Marcelo, P. Andrés and Q. Eduardo (2011). Operator experience of HPGe Cryo-Cycle detector installation at the ARP03 station, 2011 Operations and Maintenance Workshop, Provisional Technical Secretariat of the Comprehensive Nuclear-Test-Ban Treaty Organization, San Diego, California.

Kumata, M. and Y. Tomita (2011). Station operation just after a big earthquake in RN38, Takasaki, Japan, 2011 Operations and Maintenance Workshop, Provisional Technical Secretariat of the Comprehensive Nuclear-Test-Ban Treaty Organization, San Diego, California.

McKinnon, A. D., S. M. Bowyer, C. W. Hubbard, H. S. Miley, R. W. Perkins, R. C. Thompson, and R. A. Warner (1998). Environmental measurements with a Comprehensive Nuclear-Test-Ban Treaty radionuclide particulate monitor, *J. Radioanal. Nuc. Chem*. 235: 115–119.

Miley, H. S., S. M. Bowyer, C. W. Hubbard, A. D. McKinnon, R. W. Perkins, R. C. Thompson, and R. A. Warner (1998). A description of the DOE Radionuclide Aerosol Sampler/Analyzer for the Comprehensive Test Ban Treaty, *J. Radioanal. Nuc. Chem.* 235: 83–87.

Suarez, R., P. E. Keller, J. C. Hayes, J. I. McIntyre, and B. T. Schrom (2009). State of health diagnostics and prognostics with SAUNA. 2009 Informal Noble Gas Experiment (INGE) Workshop, Daejaeon, South Korea.

Yocum, K. M., G. N. Matin, J. F. Colaresi, and H. S. Miley (2008). Improvement in Ge detector cooling, in *Proceedings of the 30th Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies*, LA-UR-08-05261, Vol. 2, pp. 824–833.

Yocum, K. M., J. Colaresi, and H. S. Miley (2010). Improvement in Ge detector cooling, in *Proceedings of the 2010 Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies*, LA-UR-10-05578, Vol. 2, pp. 636–644.