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Real-time airborne radiation analysis and collection (RTARAC) searching for airborne species characteristic to nuclear proliferation

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An effective means of detecting airborne radioactive aerosol plumes has been developed and tested on aircraft platforms. The Real-Time Airborne Radiation Analysis and Collection (RTARAC) system was mounted in the wing pod of a Navy P-3 where it sampled 20 cubic meters of air per minute on each of eleven sequentially advanced filters. A 140% intrinsic germanium detector counted radioactive particles collected on the 15 cm circular filters in real-time. Gamma-energy spectrum and near real-time analysis of the sample were displayed on a laptop computer.

Introduction*

Nuclear weapons tests, reactor operations, fuels reprocessing, nuclear accidents, and radioactive spills all call for the ability to measure an airborne radioactive particulate plume and report results in real time. The Real Time Airborne Radionuclide Analysis and Collection (RTARAC) instrument has been developed by the U.S. DOE at PNNL (Fig. 1). As part of the Airborne Multisensor Pod System (AMPS), the RTARAC is designed to operate while mounted in the wing pod of a P-3 Orion aircraft. The RTARAC has been flight tested on a US Navy P-3 platform as well as the PNNL Grumman Gulfstream-I. Airflow through a 15 cm intake duct deposits particulate material on a 182-cm^2 circular filter cartridge. A 140% intrinsic germanium detector (IGe) continuously monitors the filter collection for gamma-emitting radionuclides. The RTARAC carries eleven filters that are sequentially advanced and retracted from the air stream. Data from the 10 missions flown to date clearly show the acquisition of radon daughter particulate background. The RTARAC filter advance mechanism and data collection parameters are controlled via Ethernet connection with a customized user interface that provides real-time system and data feedback. Employing the collected background spectra, the sensitivity of the RTARAC to various nuclear proliferation signatures has been shown to be significant and capable of locating low activity plumes.

The challenge of detecting radioactive aerosol plumes

In the event of a substantial release of radioactive aerosol to the atmosphere, it is important to be able to quickly determine the concentration, content, and the extent of the radioactive plume. Continuous low level effluent plumes may also be a concern where nuclear weapons proliferation is suspected. Instrumentation capable of assessing the radionuclide content of the plume in question must be reliable and quick to deploy. The unpredictable nature of atmospheric plumes may carry effluents along almost any path. Low altitude plumes are common, but high altitude paths can result from explosions or fires. Aerosol concentration decreases with time and distance from the source due to atmospheric mixing and diffusion. Some characteristic radionuclide effluents from proliferation processes have short half lives and must be collected soon after release to measure reportable quantities. Assessment of airborne radioactive aerosols in critical situations requires the ability to position a collection and detection system in the plume near the source. In addition, real time detection and analysis is required to locate small plumes or plumes of unknown origin. Archival of aerosol collections is also desirable for the purpose of post collection detailed laboratory analysis.

Experimental

Considering the scenario requirements of low level plume detection and analysis, staff at Pacific Northwest National Laboratory (PNNL) developed the Real-Time Airborne Radionuclide Analysis and Collection system (RTARAC). Mounted in wing pod of a long range aircraft like the P-3 Orion, or the C-130, the RTARAC can be deployed to remote locations yet still sample at altitudes between 200 and 30,000 feet Above Ground Level (AGL). The wing pod mounting eliminates the need for dedicated aircraft giving the user deployment flexibility and reduced costs. The pod position also permits the collection of undisturbed air and reduces the risk of losing particulates through turbulent or static deposition on the aircraft body.

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Fig. 1. The RTARAC was installed in the U.S. DOE AMPS Effluent Species Identification Pod and tested during flights on the U.S. Naval Research Laboratory's P-3 aircraft in the summer of 1996. The RTARAC performed exceptionally well, collecting over 1500 spectra on more than 80 filters automatically

To assist in detecting small radionuclide concentrations, particulates are concentrated on a filter media which samples 20 m^3 of air per minute. This volume is directly measured with an RTD anemometer calibrated to ground based velocity experiments and verified by pressure differential tests. Air is forced through a 15 cm diameter intake by the forward motion of the aircraft. The aircraft cruises at a velocity of about 220 knots. A matrix of permanently charged rectangular polypropylene fibers composes the 3M Filtrete™ media selected for use in the RTARAC. A circular shuttle mechanism rotated by a computer controlled servo motor advances individual filter cartridges from the spring loaded supply magazine into the sample air stream. When particulate collection is complete, the shuttle advances the filter to the unload position where it is archived in a storage magazine for post flight examination and analysis. The shuttle repeats the load, sample, and unload sequence for each of the eleven filter cartridges in the supply magazine. RTARAC filter cartridges consist of two machined aluminum rings that bolt together around the circular filter media and a stainless steel backup screen. This design allows future testing of a variety of filter media.

Differentiating between natural airborne background species and low concentrations of characteristic nuclear proliferation effluents requires the use of a high resolution gamma detection system. A 140% intrinsic germanium detector was selected to perform rapid acquisition of low activity samples. The detector is contained in a 10 cm diameter aluminum canister 1 mm thick and 29 cm long. The detector has a 1.5 mm dead layer, is 8.3 cm in diameter 10.9 cm in length, has a 140% relative efficiency, and has a resolution of 2.02 keV FWHM at the ^{60}Co 1.332 MeV line. A short 90° cryostat arm connects the detector to a 6 liter liquid nitrogen Dewar that provides 69 hours of operation between refills. Placed less than 2 cm behind the collection filter, the germanium detector is in a good location for detecting gamma-rays emitted from the collected particulates. A 1 mm thick aerodynamically shaped aluminum cover protects the germanium detector from flying debris that may penetrate the filter and screen.

Background radiation and physical noise reduction techniques enhance the ability of the RTARAC to detect low concentrations of particulate radionuclides on the filter. SYNTH,[1] a gamma-spectrum synthesizer software package was used to model the RTARAC detector and the surrounding background environment. ^{40}K, ^{232}Th, ^{235}U, ^{238}U, and all of the background daughter products were included in the SYNTH model. It was found that by adding a 0.63 cm thick tungsten shield around the detector that the background signal could be reduced by 68%. An 11.7 cm long by 11.2 cm inside diameter ×0.63 cm wall tungsten cylindrical shield is centered over the forward looking germanium detector and does significantly reduce background counts. This shield effectively improves the minimum detectable concentration by eliminating background counts while having no effect on gamma-rays emitted from the sample.

Physical noise and vibration are a significant problem in the typical RTARAC installation. The wing pod position on the Lockheed P-3 test platform is within 3 meters of one of four 4500 HP turboprop engines that power the aircraft. To protect the detector from overwhelming vibration and noise, the entire Dewar and detector assembly is mounted on potted rubber vibration dampening mounts. In addition, sound absorbing rubber sheeting has been wrapped around the detector canister, cryostat, and Dewar. Testing showed that these methods worked to significantly reduce microphonic noise in the detector and allowed it to survive the harsh vibration environment.

High humidity conditions are common in the flight environment. To prevent damage, all of the RTARAC electronics are packaged in a single weather tight vibration dampened aluminum enclosure. The germanium detector and pre-amplifier have also been sealed to prevent moisture from entering. With these precautions taken, the RTARAC unit is rain proof.

During a typical mission, the RTARAC collects and stores an 8000 channel gamma-spectrum every 2–30 seconds. These files are archived on a 20 Mbytes flash memory card and can be called up for future reference during or after the mission. At two-second intervals, a simple gamma analysis routine is run on the current acquisition spectrum. The results of this analysis are constantly updated and displayed on the operator screen. The operator can view the actual spectrum as it develops or can watch count rate and peak analysis displayed in a table of pre-defined characteristic radionuclides of interest. The user interface and analysis display are designed to provide the operator with a definite location and time that the aircraft encountered measurable quantities of specific radionuclides above background levels. In conjunction with GPS data input, the RTARAC program will map the flight path of the aircraft and place graphical markers in places where positive results were found. Using meteorological and wind data, an analyst can formulate the

origin of an effluent plume for further investigation or predict its future path.

Results

The RTARAC system was first tested on the ground with the assistance of a 15 horsepower Roots Blower air pump. This unit provided adequate simulation of in flight airflow to test the mechanical function of the RTARAC. After almost 200 successful filter advances without any failures, staff were assured that the unit would perform mechanically under the stresses of flight. In addition, particulate collection efficiencies were confirmed for background radionuclides by comparing Filtrete™ with micro pore filter collections. Efficiencies of 60% or greater were found for particle sizes of 0.1 μm and larger at a face velocity of 15 meters per second. Ground tests also showed that cross contamination between filters within the archive magazine was un-measurable.

The first flight tests were carried out on the PNNL twin turboprop, 18 passenger Grumman Gulfstream (G-1). The RTARAC was mounted in the empty fuselage of the G-1. Intake and exhaust ducts transported air through a modified window port to the RTARAC. The G-1 provided an inexpensive platform for initial flight testing and background collections. The RTARAC performed well, collecting distinct high resolution background spectra and successfully advancing and archiving all eleven filter cartridges on both three hour flights. Expected decreases were recorded in radon daughter concentrations with increasing collection altitude. Collection elevations ranged from 500 to 22,000 feet AGL. Resolution and gain on the detector were both remarkably stable during the G-1 tests.

The RTARAC was mounted in the AMPS ESI pod in July, 1996 and flown over various portions of the continental U.S. with the NRL P-3 Orion test platform. Over the course of ten flights and eight collection missions, operators proved the physical performance of the RTARAC in extreme flight conditions. During mission eight, a variety of flight conditions were encountered. Forces due to turning, climbing, descending, bouncing and vibration were all experienced through their normal ranges. Mechanical cycling of the RTARAC filter changing system proved to be 100% effective during all modes of flight and through many combinations. The temperature of the pod exterior would often change dramatically and rapidly during accent and descent. These changes seemed to have no effect on the mechanical operation of the RTARAC. High humidity was also experienced after descending from low temperature high altitude flight. Problems associated with condensation buildup were not realized. Post flight inspection showed that the instrument was covered with water, but no adverse effects were observed. During each flight, eleven filter cartridges were cycled through the system. Since only background collections were expected, spectra files were only saved at a rate of one every two minutes during each of the five-hour flights. Collection elevations ranged from 500 to 10,000 feet AGL. As with the G-1 test flights, only background radionuclides were found. Stable gain and resolution during the P-3 flights, however, proved the design of the RTARAC vibration isolation methods and the general quality of the design.

Fig. 2. The bottom smoothed gamma-spectra is an actual background collection at 2000 ft. above mean sea level (MSL). The upper smoothed spectrum is identical except for the addition of synthesized ^{138}Cs gamma-peaks. The ^{138}Cs spectrum is elevated by 20 counts for visual clarity. ^{138}Cs is modeled at a concentration of 125 Bq/m^3. The collection and count time is 22 minutes. The flow rate is 20 m^3/minute. The collection efficiency is set at 70%. Under these conditions, ^{138}Cs is measured at 10 sigma above background

An example of a background spectrum collected and counted for 22 minutes at 2000 feet above mean sea level (MSL) is shown as the lower curve of Fig. 2. The elevated spectrum in the figure is the same background data with a synthesized ^{138}Cs spectrum added. The two spectra are offset by 20 counts and smoothed for visual clarity. Synthesized at an atmospheric concentration of 0.125 Bq/m^3, the ^{138}Cs peaks are measured at 10 sigma above background. ^{138}Cs, ^{89}Rb, ^{139}Ba-^{139}Cs, ^{140}Ba-^{140}La and other characteristic radionuclides can all be measured at concentrations in the range of 10^{-2} to 10^{-1} Bq/m^3 with similar certainty.

Conclusions

The purpose of developing the RTARAC was to discover, examine, and solve the complexities of real-time airborne particulate radionuclide collection, analysis, and archival. This has been accomplished. In addition to providing the user with real time radionuclide data, the RTARAC software allows data to be integrated into the AMPS or other similar data fusion systems. Proven rugged design, flexible deployment capabilities, and multiple mission scenarios make the RTARAC a valuable tool for those who wish to find, track, quantify, and verify the existence of airborne particulate radionuclides.

Reference

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