Defence Research and Development Canada | Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Completion report for CRTI 07-0103RD

"Full-Scale RDD Experiments and Models"

Dr. Lorne Erhardt, Ms. Debora Quayle and Mr. Scott Noel

Defence R&D Canada – Ottawa

Canada

Technical Report
DRDC Ottawa TR 2013-056
October 2013

Completion report for CRTI 07-0103RD

"Full-Scale RDD Experiments and Models"

Dr. Lorne Erhardt
DRDC Ottawa, Radiological Analysis and Defence Group

Ms. Debora Quayle
Health Canada, Radiation Protection Bureau

Mr. Scott Noel
International Safety Research

Defence R&D Canada – Ottawa

Technical Report
DRDC Ottawa TR 2013-056
October 2013

Principal Author

Original signed by Dr. Lorne Erhardt

Dr. Lorne Erhardt

Defence Scientist

Approved by

Original signed by Bill Katsube

Bill Katsube

Section Head, RNN Section, DRDC Ottawa

Approved for release by

Original signed by Chris McMillan

Chris McMillan

Chief Scientist, DRDC Ottawa

This work was sponsored by DRDC Centre for Security Science under project number 07-0103RD.

Abstract

In order to gather more and more accurate information on the behaviour of Radiological Dispersion Devices (RDDs), a set of experiments was performed. These experiments built on the existing body of knowledge and included many of the world's leading authorities in RDD physics, modelling and atmospheric dispersion. Beginning with indoor tests to characterize the explosive used to perform the dispersion of our radioisotope, the experiments culminated in a series of three outdoor releases of a short-lived tracer isotope, ^{140}La.

The dispersion and deposition from these outdoor explosive releases were monitored and recorded using a wide variety of instruments. Radiation was monitored using fixed point large volume gamma detectors, a large number of small volume gamma detectors (260), truck and helicopter mounted spectrometry equipment, hand-held survey instruments, and air-samplers. Weather conditions were monitored from three mobile meteorological stations, as well as through the launching of weather balloons. There were also LIDAR, high speed video, and wide-field video monitoring of the explosions and subsequent plumes.

The unique data sets gathered during these releases fed existing RDD modelling efforts and will be shared with our allies to inform future generations of models and risk assessments.

Résumé

Une série d'expériences a été effectuée afin de recueillir des informations plus nombreuses et plus précises sur le comportement des dispositifs de dispersion radiologique (DDR). Ces expériences étaient fondées sur l'ensemble des connaissances existantes et elles incluaient celles de nombreuses sommités du monde de la physique et de la modélisation des DDR et de la dispersion atmosphérique. En commençant par des tests effectués à l'intérieur afin de caractériser l'explosif utilisé pour effectuer la dispersion de notre radioisotope, les expériences se sont conclues avec une série de trois rejets en plein air d'un traceur isotopique à courte vie, le ^{140}La.

La dispersion et le dépôt de ces rejets d'explosion en plein air ont été surveillés et enregistrés en utilisant une grande variété d'instruments. Le rayonnement a été contrôlé à l'aide de détecteurs gamma fixes à grand volume, d'un grand nombre de petits détecteurs de rayonnement gamma à petit volume (260), d'équipements de spectrométrie embarqués dans des camions et hélicoptères, des instruments de mesure à main et des échantillonneurs d'air. Les conditions météorologiques ont été suivies à partir de trois stations météorologiques mobiles, y compris des ballons météorologiques. On a aussi effectué la surveillance des explosions et des panaches ultérieurs par LIDAR, vidéo haute vitesse et vidéo à champ étendu.

Les jeux de données uniques recueillis au cours de ces rejets ont alimenté les travaux de modélisation des DDR en cours et ils seront partagés avec nos alliés pour donner forme aux futures générations de modèles et pratiques d'évaluation des risques.

This page intentionally left blank.

Executive summary

Completion report for CRTI 07-0103RD: "Full-Scale RDD Experiments and Models"

Lorne Erhardt; Debora Quayle; Scott Noel; DRDC Ottawa TR 2013-056; Defence R&D Canada – Ottawa; October 2013.

Introduction or background: Project CRTI 07-0103RD "Full-Scale Radiological Dispersal Device Experiments and Models" was funded by the DRDC Centre for Security Science (CSS) in order to characterize the real-world effects of radiological dispersal devices (RDDs) better and to allow Canada to be better prepared to respond to them. This project, led by DRDC Ottawa, spanned five years and involved a total of 18 national and international organizations, 9 of which were official project partners. The project involved both an experimental stream and a modelling stream. The modelling stream investigated how best to integrate physics models relevant to the different time and distance scales involved in an RDD. The experimental stream involved a series of experiments with inert (non-radioactive) material designed to characterize the explosive dispersal device that was later reproduced for full-scale outdoor dispersal experiments using a short-lived radioactive material as a tracer.

Results: The modelling stream resulted in a method for taking the output of an AUTODYN hydrocode simulation and using that as an input to the computational fluid dynamics code CFX while conserving energy and momentum. Outputs of the modelling stream have been transferred to international partners and to industry for exploitation. The culmination of the experimental stream was a series of three explosive dispersal experiments that were carried out in the spring and fall of 2012 on the DRDC Suffield Experimental Proving Grounds. These trials resulted in an extensive dataset from a wide variety of instruments and detection systems. These systems measured the near-real-time passage of the plume, the deposition on the ground, and the meteorological conditions of the trials in great detail. The result is a unique set of data from outdoor radioactive dispersals, spanning all distance and time scales of an RDD event from the explosive shock wave travelling through the material to the plume formation and evolution to deposition.

Significance: As a result of this project Canada and its allies have a better understanding of RDD events and enhanced capabilities in consequence prediction and response planning. These enhanced capabilities include better modelling tools, procedures for working in large-scale contaminated environments, methods for joint response and tools for collecting and interpreting field data from a variety of operational detection systems. These capability enhancements apply in both a civilian and military context.

Future plans: In the coming months to years the project team will publish results in both open literature and internal documents. This will ensure that end-users of these results are aware of the work that has been performed under this project. Thorough documentation will also help maintain our capability to perform similar field experimental work in the future.

This page intentionally left blank.

Sommaire

Completion report for CRTI 07-0103RD: "Full-Scale RDD Experiments and Models"

Lorne Erhardt; Debora Quayle; Scott Noel ; DRDC Ottawa TR 2013-056 ; R & D pour la défense Canada – Ottawa; octobre 2013.

Introduction ou contexte : Le projet IRTC 07-0103RD, Expériences et modèles de dispositifs de dispersion radiologique pleine échelle, a été financé par le Centre des sciences pour la sécurité (CSS) de RDDC afin de mieux caractériser les effets des dispositifs de dispersion radiologique (DDR) dans le du monde réel et pour permettre au Canada d'être mieux préparé à y répondre. Ce projet, dirigé par RDDC Ottawa, s'étend sur cinq ans et un total de 18 organisations nationales et internationales, dont 9 étaient des partenaires officiels du projet, y participait. Le projet comportait à la fois un flux expérimental et un flux de modélisation. Le flux de modélisation étudiait la meilleure façon d'intégrer les modèles physiques pertinents aux différentes échelles de temps et de distance liées aux DDR. Le flux expérimental comportait une série d'expériences avec de la matière inerte (non radioactive) qui avaient été conçues pour caractériser le dispositif de dispersion explosive qui a ensuite été reproduit pour effectuer des expériences de dispersion en plein air à pleine échelle à l'aide d'une matière radioactive de courte période comme traceur.

Résultats : Le flux de modélisation a abouti à une méthode permettant d'utiliser les extrants d'une simulation réalisée avec l'hydrocode Autodyn comme intrants pour des calculs effectués avec le code de calcul de dynamique des fluides CFX tout en conservant l'énergie et le moment. Les extrants du flux de modélisation ont été transférés aux partenaires internationaux et à l'industrie en vue de leur exploitation. Le point culminant du flux expérimental a été une série de trois expériences de dispersion par explosifs effectuées au printemps et à l'automne 2012 au Polygone d'expérimentation et d'essais de RDDC Suffield. Ces essais ont produit un vaste jeu de données provenant d'une grande variété d'instruments et de systèmes de détection. Ces systèmes ont mesuré le passage en temps quasi réel du panache, le dépôt de matière sur le terrain et les conditions météorologiques des essais dans les moindres détails. Les données recueillies constituent un ensemble unique de données provenant de dispersions radioactives en plein air, couvrant toutes les échelles de distance et de temps d'un événement DDR, du déplacement de l'onde de choc de l'explosion à travers le matériau jusqu'à la formation d'un panache et son évolution jusqu'au dépôt de matière.

Importance : À la suite de ce projet, le Canada et ses alliés ont une meilleure compréhension des événements DDR et ils disposent de capacités améliorées en matière de prévision des conséquences et de planification des interventions. Ces capacités améliorées comprennent de meilleurs outils de modélisation, des procédures de travail dans des environnements contaminés à grande échelle, des méthodes d'intervention conjointe et des outils pour la collecte et l'interprétation des données sur le terrain à partir d'une variété de systèmes de détection. Ces améliorations des capacités s'appliquent aux contextes civils et militaires.

Perspectives : Au cours des prochains mois, voire des prochaines années, l'équipe du projet publiera des résultats. Cela prendra la forme d'articles dans des publications publiques et dans des

publications internes afin d'informer les utilisateurs finals de ces résultats et de maintenir notre capacité d'effectuer éventuellement des travaux expérimentaux dans des domaines semblables.

Table of contents

List of figures

List of tables

This page intentionally left blank.

Acknowledgements

This work was supported by Defence Research and Development Canada (DRDC) Centre for Security Science through the Chemical, Biological, Radiological/Nuclear, and Explosives Research and Technology Initiative (under project title: CRTI 07-0103RD Full Scale RDD Experiments and Models).

Project Partners:

- Defence R&D Canada – Ottawa
- Defence R&D Canada – Suffield
- Defence R&D Canada – Valcartier
- Health Canada, Radiation Protection Bureau – HC RPB
- Environment Canada, Canadian Meteorological Centre – EC CMC
- Natural Resources Canada – NRCan
- Royal Military College – RMC
- Canadian Border Services Agency – CBSA
- International Safety Research Inc. – ISR
  - Acadia University (sub-contract)
  - SimuTech Group Inc. (sub-contract)

With gracious participation by:

- UK Atomic Weapons Establishment – AWE
- US Department of Energy – DOE
  - National Nuclear Security Administration – NNSA
  - Sandia National Laboratories – SNL
  - Remote Sensing Laboratories – RSL
  - Pacific Northwest National Laboratories – PNNL
  - National Atmospheric Release Advisory Center – NARAC
- DRDC Centre for Security Science – DRDC CSS
- Atomic Energy of Canada Limited – AECL
- Canadian Joint Incident Response Unit – CJIRU
- University of Alberta SLOWPOKE Nuclear Reactor Facility (contract)

This page intentionally left blank.

1 Introduction

Terrorist use of a Radiological Dispersion Device (RDD) is recognized in Canada as a significant threat [1]. Due to the lack of high-precision, high-confidence and experimentally benchmarked modelling tools, current RDD response planning could be significantly overly conservative, or not sufficiently stringent. To help shed light on this uncertainty, CRTI funded Project # CRTI-07-0103RD (Full-Scale RDD Experiments and Models) led by DRDC Ottawa. This project provides a consolidated set of data from experiments and field trials and sets the ground work for improved RDD effect models for consequence estimation before and/or after an explosive RDD event.

The project accomplished this by studying a series of actual explosive dispersions of short-lived radioactive material simulating RDD threat material. The radioisotope used (^{140}La) has a short half-life (40 hours), making it possible to gather realistic data easily without risk to personnel or the environment. These real-world data were used to inform an improved set of RDD modelling toolkits and to increase the general understanding of RDD threats within the Canadian federal government and our allies.

1.1 Purpose

The overall purpose of the project was to improve Canada's ability to prepare for, respond to and recover from an RDD attack by providing high fidelity data sets for characterizing RDD effects. In order to achieve this, a secondary goal was the establishment of a team with the diverse skills required to prepare and perform the experiments and analyse the data produced.

Preparing this team required an investment in training, equipment procurement and in some cases equipment design and fabrication. The level of cooperation was substantial and the result has been excellent data and the creation of a team of experts who are now eminently qualified to provide advice and assistance in the event of a real-world RDD incident. Additionally, intercomparisons between operational detection systems in a realistic contamination environment provide experience and confidence in field measurements.

1.2 Links to CSS Capabilities

This is linked to the following CSS capabilities: Threat Intelligence (Ex1) and Consequence Management (Ex4).

1.2.1 Explosives (Ex 1 – Threat Intelligence)

The DRDC Centre for Security Science currently uses the CRTI Consolidated Risk Assessment [1] to weigh the relative risks of a variety of CBRN threats. The Probabilistic Risk Assessment Tool developed by DRDC Ottawa (PRA Tool, CRTI 02-0024RD) is also currently used to assess the relative risks associated with various radiological weapon threats. Both of these risk assessments will benefit from the data delivered by this project, given the exhaustive work performed characterizing all aspects of the experimental device and its post-detonation effects.

1.2.2 Explosives (Ex 4 – Consequence Management)

While most dispersion modelling codes are adequate for modeling long range dispersion, they are not optimized for ranges below 500 meters which is the area of primary health concern in the case of radiological dispersal devices. This project links a wealth of previous indoor source term[1] experiments [2-4] with real-world outdoor dispersion trials, providing unique and invaluable information on short-range dispersion patterns along with links to long-range dispersion patterns as calculated using typical dispersion modelling codes.

1.3 Project scale

In order to accomplish the goals set out at project inception, a large research collaboration was established. Ultimately the scale of the project exceeded the initial expectations. At the conclusion of the five year project, there were nine full project partners, several sub-contractors, three Canadian government department participants (non-partners), and six participating agencies from the United States and the United Kingdom.

Figure 1 gives an indication of the scale of the outdoor experiments. The large cluster of trailers and tents in the left of the photo is the base camp, the smaller group of trailers and tents in the middle is the decontamination facility, and the white 18-wheeler towards the right of the frame is the lidar trailer (see section 3.2.2.3 for a description of the lidar system). The green circle is a 100 m radius area cleared for ground zero (GZ); this area contained a tightly clustered array of detectors. Because of the scale of the photo, it is impossible to see individual detectors, the 10 meter towers, and the wildlife exclusion fence (a fence erected to keep the local animals away from ground zero). The exclusion zone, meaning the area reserved for the experiment, extends for several kilometers beyond what Figure 1 shows.

Figure 1: Trial site at DRDC Suffield illustrating the large scale of the experiments. Photo does not show the far-field detectors.

[1] "Source term" is the amount and particle size distribution of the aerosol generated by a dispersal device

1.4 Scope

With the evolving realities of the project, the scope unavoidably evolved, increasing in some areas and decreasing in others.

With shifting priorities and loss of personnel, the DRDC Ottawa modelling effort was discontinued. This necessitated a reduction in the scope of the modelling stream, and the shifting of modelling tasks to project partners. Modelling did continue, with project funds being spent on sub-contracted modelling work (SimuTech Group Inc.) and an increased in-kind effort by the UK Atomic Weapons Establishment, who stepped up to merge modelling from the RDD project with their existing and ongoing source-term modelling efforts.

With modelling commitments being partially absorbed by a third party (AWE), remaining project modelling funds were reallocated for experiment execution and contributed to the successful completion of three full-scale outdoor releases.

This change in scope and the transitioning of the remaining modelling to international participants (US & UK) was approved during the Project Review Committee Meeting (20 November 2012).

2 Methods

Any discussion of methodology must stress foremost, the disparate subject matter experts and teams that had to be assembled and work together towards common goals. There were many aspects of this project that could have easily formed the basis of a separate project (creation of radiation data logging devices, model review and integration, creation of a new LIDAR system, *et cetera*).

2.1 Overview

This project comprised two parallel streams:

1. An experimental stream, and

2. A modelling refinement stream.

The two streams were integrally linked. The experiment design was, to a large extent, informed by gaps in the existing modelling approaches. Many of the experiment parameters were devised specifically to provide input for models (e.g. explosive device design). Almost all of the data collection was determined by the input requirements for the modellers (meteorological data, location and frequency of radiation detection equipment, *et cetera*).

2.2 Experimental methods

The experimentation stream consisted of three phases: Indoor experiments with inert material, outdoor experiments with inert material, and full-scale outdoor experiments using short-lived radioactive material.

2.2.1 Indoor experiments with inert material:

The indoor experiments were conducted to characterize the shape and size of the La_2O_3 particles post-blast. The explosive device was the same design as was later used in the outdoor field trials. Results were used to refine the input parameters for the selected modelling algorithms, and to provide information for the development of the outdoor tests.

- The experimental explosions were performed by RMC and by SNL.
- Analysis of the resulting debris was performed by HC and SNL (particle size) and Acadia University (particle morphology).

2.2.2 Outdoor experiments with inert material:

Outdoor trials using the proposed device, detonation system, and payload were conducted in order to confirm that the device worked as expected, to practice procedures for loading the radioactive source and identify potential issues ahead of time, and to time the process to facilitate scheduling

on the days of the shots. Both regular and high-speed video were recorded to capture characteristics of the device immediately post-blast and until atmospheric transport mechanisms carried the plume downwind. Additionally, flash x-ray images were obtained showing the detonation wave moving through the explosive device and the resulting effects on the payload (compression, acceleration, *et cetera*).

– These tests were done by DRDC Suffield and DRDC Valcartier.

2.2.3 Full-scale outdoor experiments:

Short-lived radioactive material (approximately 37 GBq of ^{140}La at each detonation) was explosively dispersed at the Experimental Proving Grounds (EPG) at DRDC Suffield, simulating actual RDD events. Lanthanum was chosen due to its short half-life (40 hours), ease of production in required quantities, and ease of detection.

This final phase was by far the most involved and difficult.

– Prior to the trials, aside from the experimental planning itself, acquiring permissions from the site and regulatory approval took several years of concerted effort.

– During the trials, it was necessary to maintain a small community of scientists, engineers, technicians, and military personnel, on the EPG for three weeks at a time. Requirements for food, water, sanitation, electricity, shelter, as well as all the support for the equipment (fuel, compressed gasses, masts, mounts, stands, *et cetera*) had to be addressed through careful planning and execution.

The data collection was done on a similarly grand scale. In order to measure and document the experimental conditions and resulting distribution of the radioactive material, the following capabilities were engaged:

- To track and/or measure atmospheric transport immediately following detonation:
  - LIDAR optical remote sensing (overseen by DRDC Valcartier);
  - High-speed videography (overseen by DRDC Suffield);
  - Near-real-time monitoring of the radiation field during the dispersion, using an array of 250 gamma detectors fixed at 1m from the ground, extending from 10m to 450m downwind (overseen by ISR);
  - Additional down-range and perimeter monitoring in near-real-time, using strategically placed RS-250 NaI detectors (overseen by HC RPB); and
  - Downrange air sampling using high-volume samplers. At several locations, air samplers were stacked vertically up to 10m. (overseen by DOE)
- To measure deposition:
  - Airborne radiation survey and mapping (overseen by NRCan);
  - Beta measurements of 350 witness plates (250 were affixed to the detector stands in the array) carried out by field teams using hand-held instruments (AB-100 and SVG-2) (overseen by DRDC Ottawa);

- Gamma measurements from the RS-250 network, calibrated for ^{140}La deposition on the ground (overseen by HC RPB);
- Gamma measurements from the data-logger array (overseen by ISR);
- Additional vehicle-borne and hand-held radiation detection systems, as appropriate (all partners); and,
- HPGe in situ measurements at selected sampling locations.

- To measure environmental conditions:
  - Sensors and sonic anemometers at 2 m, 4.5 m and 12 m (10 m in trial 3) to track and record temperature, three-dimensional wind speed, and wind direction (overseen by DRDC Ottawa and DRDC Suffield);
  - Radiosondes (balloon-mounted sensors) to characterize temperature and wind profile above 12 m (overseen by DND CF); and
  - One on-site meteorological station to monitor conditions in real-time (overseen by DRDC Ottawa and DND CF).

The nominal layout of fixed equipment is shown in Figure 2.

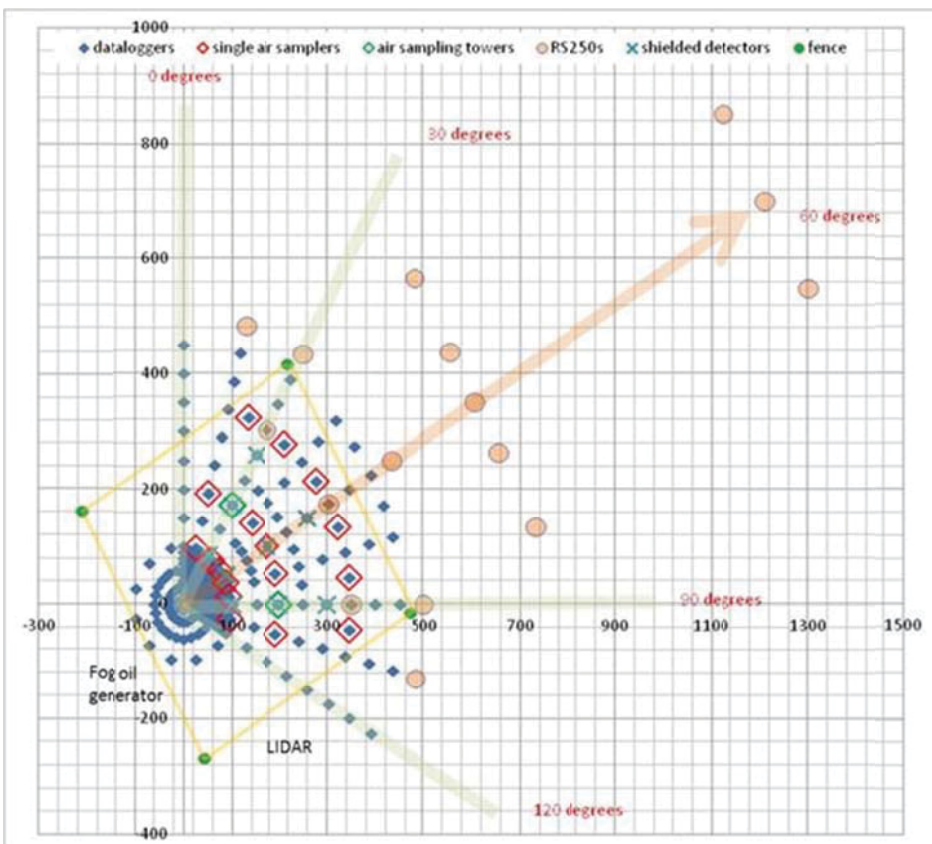

Figure 2: Layout for fixed detection equipment. Data-loggers were positioned at 10m intervals within a 100m radius from GZ, then at roughly 50m intervals, with some staggering, downrange.

Air samplers were mounted at 10m on each tower. Far-field air samplers are not shown. Met tower (not shown) was approximately 20m upwind from GZ.

More information (type of equipment deployed and operational plans) can be found in the Field Trial Plan (FTP) [5], the Experiment Plan [6] and in the After Action Report [7], as well as in individual publications from the group and from individual partners (See Annex C).

2.3 Modelling methods

Previous CRTI projects 02-0024RD & 03-0018RD have experimentally examined aspects of RDDs and developed models to better understand the physical phenomena involved. They served to highlight the need to expand the scope of the experiments and models in order to produce modelling tools capable of predicting the real-world behaviour of an RDD.

The original project plan included an agent-based modelling approach. This was dropped from the scope of the project due to international contracting issues and loss of key personnel at DRDC Ottawa (approved at the 12 January 2011 Project review Committee Meeting). This approach will therefore not be discussed further in this report.

2.3.1 Model investigation and acquisition

The modeling stream began with the comprehensive and systematic investigation and acquisition of 'best-of-breed' computer simulations for RDD events in terms of each code's functionality and underlying infrastructure. Codes acquired were not simple one-size-fits-all RDD modelling codes, but disparate codes designed to model individual characteristics of physical events. In the case of RDDs, fireball physics, hot gas transport, and transition to atmospheric dispersion codes needed to be investigated, specifically the following:

- Finite element solvers for computational structural dynamics (FE)
- Finite volume solvers for fast transient Computational Fluid Dynamics (CFD and CFX)
- Mesh free particle solvers for high velocities, large deformation and fragmentation (SPH)
- Multi-solver coupling for multi-physics solutions including coupling between FE, CFD and SPH

Once the basic building-blocks (disparate algorithms) were chosen, they were combined. A basic modelling "footprint" was established. This work was done by the DRDC Ottawa Synthetic Environments Group and by David Cornwell, a subcontractor to ISR.

2.3.2 Model validation

Simply combining the codes is not a trivial task. The footprint was established with the most rudimentary combination. As the different algorithms reflect the different physics from each stage of the event (i.e. fireball physics takes place over very short distances at very high energies, whereas atmospheric dispersion takes place over large distances at very low energies), the output of one algorithm is poorly suited to feed the input of the subsequent algorithm.

Significant modification to the code and to the user interfaces (that allow manipulation of data through the codes) was undertaken. The codes had to demonstrate that both mass and energy were conserved when moving from one set of algorithms to the next (i.e. fireball to rising gas to atmospheric dispersion). This work was done by SimuTech Group Inc (subcontractor to ISR) with oversight by the DRDC Ottawa Synthetic Environments Group.

2.3.3 Model refinement

The linked modelling code was shared with the AWE group with the goal of using the data from the live outdoor trials to verify the function and to refine the performance of the code. This work is currently being performed by AWE

The further step of modifying existing RDD dispersion code has also been undertaken. Modifications to existing atmospheric dispersion codes are being explored by AWE, EC and HC. ISR is interested in incorporating the results into their commercially available suite of training software (S3EXERCISE). DRDC Centre for Security Science has recently received a proposal for a Community Development Study to perform an inter-comparison between three Canadian RDD dispersion modelling codes using the data from this project as a benchmark. The study will compare a new code being developed at Atomic Energy of Canada Limited to existing codes in use operationally by Environment Canada and Health Canada.

3 Results

The following section gives a high-level description of the results of the project in general and the trials in particular. More in-depth results are beyond the scope of this report, and will be published elsewhere. Preliminary experimental results were presented by the project team members at the US/UK/Canada Conference on Full-Scale RDD Field Trials in February 2013. The presentations and discussion from that meeting will be published in a DRDC Ottawa Technical Note, but are listed here in section C.2. Finalized results will be presented and published in a mix of internal and open meetings, conferences and journals.

3.1 Overview

The initial project proposal [11] identified four core results:

1. High fidelity field data from live RDD detonations constructed from those scenarios currently ranked "highest risk". This will be a first-of-a-kind RDD characterization data set.
   - This has been fully achieved. Discussion of the individual data sets can be found below in section 3.2.

2. Modeling code capable of customizable source-term manipulation. This innovation will significantly expand our understanding of RDD events, while providing the ability to tailor preparedness and response protocols for different scenarios.
   - This is an on-going effort; the progress is discussed in section 3.3.

3. Arsenal of detection and monitoring techniques tailored to real-world radiation dispersal events (intentional or accidental) by a collaboration of internationally recognized CBRNE experts. Many of Canada's leading members of the CBRNE/nuclear emergency response community participated in the outdoor live exercises, with both traditional tried-and-true detection systems as well as new technology (e.g., RadEye Dataloggers, Truckborne monitors). The inter-organizational cooperation and experience is expected to help define the shape of future CBRNE/nuclear emergency response collaborations, and refine operational protocols.
   - This result exceeded expectation, with initially unexpected participation by many groups, and the development of new tools and techniques. A more detailed discussion can be found in section 3.4.

4. "Leave-behinds" i) The protocols, radiological safety management plan and S3-FAST detection system for the Counter Terrorism Technology Centre (CTTC) allowing for future RDD explosion testing/exercising. ii) A Centre of Excellence (COE) created at DRDC Ottawa providing RDD modelling and risk assessment capability.
   - The protocols are all recorded and ready to be modified for future trials [5-7,9]. The equipment (S3-FAST software and 10 data-logging devices with the remote server, several hundred detector field enclosures and witness plates) has been left with DRDC Ottawa rather than DRDC Suffield.

- The idea of a modelling COE at DRDC Ottawa was dropped due to shifting DRDC priorities and loss of personnel. This is partially achieved through a wide reach-back capability rather than a single "center".

3.2 Experimental results

There was a large amount of experimental data collected over the course of this project, both during the preparations for the trials (e.g. tests with inert materials, instrument characterization) and during the field trials in spring and fall of 2012. Analyses of the field data are still in their in preliminary stages, and will likely take years to complete. What follows is a brief description of the collected data and preliminary results with references to more detailed work.

3.2.1 Results from experiments prior to the field trials

In the lead up to the RDD field trials, there were a number of experiments performed to characterize the device used in the field trials, to determine the expected "source-term" for the outdoor dispersions. These experiments included the following:

- Indoor dispersion experiments using inert material at Sandia National Laboratories (SNL) to determine the initial particle size distribution of the lanthanum
- Small-scale enclosed explosive dispersal experiments using inert material at Royal Military College (RMC) to determine parameters (e.g. dirt entrainment, water content in the fireball) that may modify the initial particle size distribution
- Semi-enclosed explosions using inert material at DRDC Valcartier to determine the dynamics of the detonation wave and the fireball temperature in the explosive device
- Outdoor explosive dispersals using inert material at DRDC Suffield to determine the fireball dimensions, ground interactions and general behavior. These tests also served as dry-runs for assembly and detonation of the device used in the field trials

The SNL indoor tests provided particle size distributions for the dispersed lanthanum oxide. An overview of how the tests were performed and the detailed particle size distribution results will be published elsewhere. In essence the tests showed that the lanthanum oxide mass was relatively evenly distributed across a range of particle sizes. Roughly a third of the dispersed mass was in the "respirable" range (<10 μm), one third in the "intermediate" size range (10 - 100 μm) and one third in the "ballistic" size range (>100 μm).

RMC completed a series of experiments dispersing lanthanum oxide powder in a small enclosed vessel (calorimeter). They studied the heat released in these explosions, varying the oxygen/nitrogen ratios in the vessel and adding a variety of soils to the vessel. They looked at changes to the resulting particle size distribution under these varied conditions. Significant modifications to the particle size distribution were observed as the fireball dynamics were altered. These results were published in Dr. Luke Lebel's Ph.D. thesis [10].

Tests at DRDC Valcartier in their semi-enclosed detonics bay used high-speed photography, flash x-ray cameras and custom fibre-optic temperature probes to determine the dynamics of the detonation wave in the test device as well as the dynamics of the resulting fireball. The results of

the x-ray imaging are closely tied to the design of the device and are therefore classified. These results were presented at the US/UK/Canada Conference on Full-Scale RDD Field Trials (see section C.2 number 13) and will be published in an internal DRDC Valcartier report, but will not be discussed here. The temperature probe results are published in Dr. Lebel's thesis [10].

High-speed and regular-speed video from the outdoor tests at DRDC Valcartier as well as similar video taken during the RDD field trials were used to determine fireball dimensions, and to compare to videos taken of the test explosions at Sandia and DRDC Valcartier. The shape and dimensions of the fireball were relatively consistent across all tests. The fireball was approximately 2.5 m to 3 m in diameter with a central upward protrusion extending to approximately 4 m to 5 m above the ground.

3.2.2 RDD field trial results

The "Full-Scale RDD Experiments and Models" project culminated in a series of three field trials in the spring and fall of 2012. The majority of the data collected in this project was collected during these three trials. Analysis of these data is an ongoing effort, spread across a number of different organizations. This report will present only a snapshot of the data collected and the early analysis. Project partners presented their preliminary results at the US/UK/Canada Conference on Full-Scale RDD Field Trials in February 2013 (see section C.2).

3.2.2.1 Field trial location and conditions

The field trials were held in the north-east corner of the DRDC Suffield Experimental Proving Ground. Figure 3 shows the trial location.

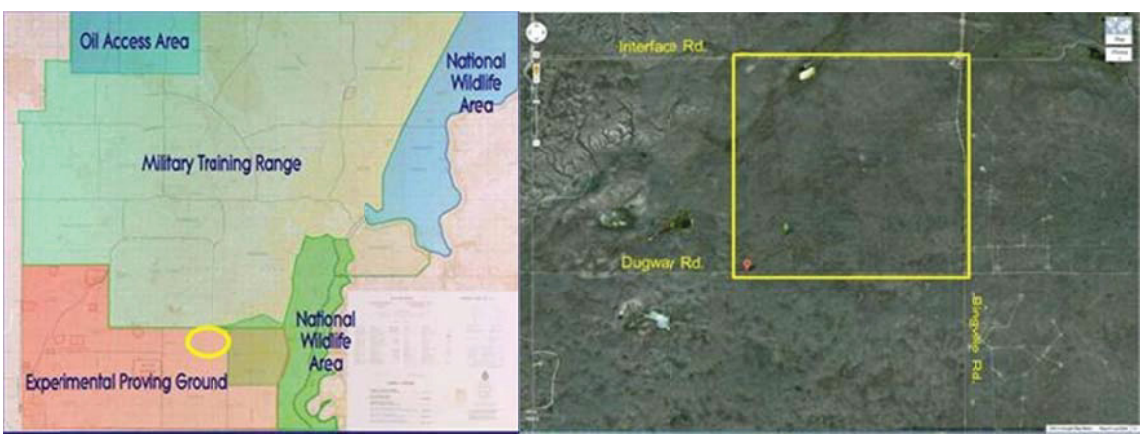

Figure 3: Trial Location at DRDC Suffield Experimental Proving ground. Left: Map of the CFB Suffield Range, showing the location of the RDD Field Trials on the DRDC Suffield Experimental Proving Ground. Right: Satellite photo with the trial location indicated.

Two dispersals were performed in the spring of 2012 and a single dispersal was performed in the fall of 2012. The parameters for these three dispersals are shown in Table 1, along with the ideal and acceptable parameters as determined in the planning phase.

Table 1: A summary of the planned acceptable and actual observed shot parameters and meteorological conditions for the three trials

	Ideal	Acceptable	Actual: Shot #1	Actual: Shot #2	Actual: Shot #3
Date	--	--	6 June 2012	12 June 2012	26 Sept. 2012
Time	--	--	0928 MDT	0938 MDT	1128 MDT
Activity (at shot time)	37 GBq	17 GBq	31.3 GBq ± 10%	36.3 GBq ± 10%	35.2 GBq ± 10%
Wind Speed	3 - 5 m/s	2 - 7 m/s	6.9 ± 1.2 m/s	4.3 ± 0.8 m/s	2.9 ± 0.4 m/s
Wind Direction	220˚ - 260˚	180˚ - 300˚	218º ± 6º	260º ± 11º	282º ± 14º
Cloud Cover	N/A	N/A	Overcast	Sunny	Overcast
Ground Condition	Dry	Moist	Dry	Dry	Moist
Precipitation Forecast	None for 72h	None for 12h	None for > 36 hrs	None for > 24 hrs	None for > 24 hrs
Temperature	5 – 20 ˚C	-5 – 30 ˚C	13.4 ˚C	18.4 ˚C	10.5 ˚C
Stability Class	Any	Any	D: Neutral	B: Moderately Unstable	C: Slightly Unstable
Inversion Layer Height	Any	Any	1350 – 1900 m	250 – 520 m	TBD

3.2.2.2 Data collection overview

An overview of the instrument suite used in the RDD Field trials was given in section 2.2.3. These instruments were designed to measure the plume passage, ground deposition and meteorological conditions for the trials. In reality, each trial had slightly different instrumentation for a variety of reasons including equipment additions and adjustments, partner availability, equipment reliability and shot conditions. A summary of which data were collected for each shot is shown in Table 2. The rest of this section gives a brief overview of the data collection systems and how they were used.

Table 2: A summary of the data collected for the three trials. An X indicates that data were collected using the indicated system. Notes indicate where there are differences in the data sets from shot to shot, or more than one type of data was collected in each category. Details of the measurements are given in sections 3.2.2.3 through 3.2.2.11.

	Shot #1	Shot #2	Shot #3
LIDAR	X	X	-
Weather Station	Base Camp	Base Camp/Fence	Base Camp/Fence
3D Wind Speed	2m, 4.5m, 12m	2m, 4.5m, 12m	2m, 4.5m, 10m
Radiosonde	Before/After	Before/After	Before/After
Air Sampling	Near/Far	Near	-
RS-250 Network – NaI	X	X	X
RadEye Array	X	X	X
Shielded RadEyes	X	X	-
Airborne – RS 700	40 m	40 m	15 m
Vehicle-borne Survey	Directional	Non-directional	Directional
MATS – Mobile Microspec	X	X	X
In-situ Gamma	HPGe	HPGe	NaI
Beta Deposition – AB-100s	X	X	X
Beta Deposition – SVG2	-	-	X
Deposition – Filters + Gamma Analyst	X	X	-
Deposition – Filters + Imaging	X	X	-
Videography	High/Normal Speed	High/Normal Speed	High/Normal Speed

3.2.2.3 LIDAR

DRDC Valcartier deployed the LIDAR Cloud Mapper to measure the plume density downwind from the dispersion. The LIDAR system uses a pulsed laser and detector system to map out the density of aerosol in the plume by measuring laser light backscattered by the aerosol particles. Details of the LIDAR system, methodology and analysis of the measurements taken are available in a DRDC Valcartier report [11] and were also presented at the US/UK/Canada Conference on Full-Scale RDD Field Trials (see section C.2 number 17). The LIDAR system is shown in Figure

4. A series of cross-sectional traces for the plume generated in shot #2 is shown in Figure 5. The LIDAR system is sensitive to all aerosols in the plume, not just the radioactive component.

Figure 4: Valcartier's LIDAR Cloud Mapper.

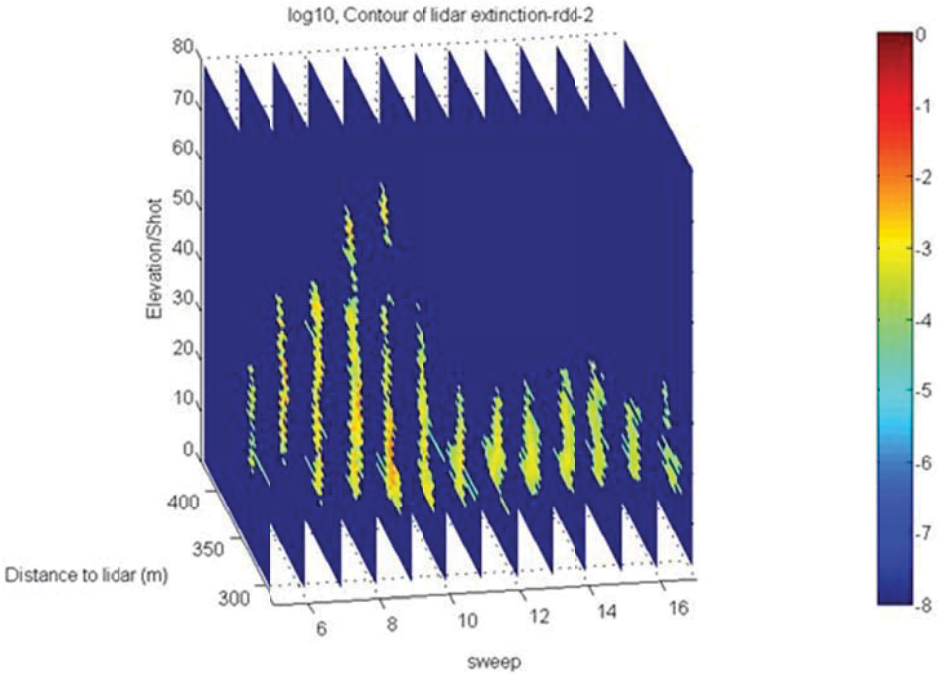

Figure 5: Time slices (sweeps) from the LIDAR Cloud Mapper for shot 2. This shows the plume density as a function of time at a specific distance downwind of the release point (approximately 100 m downwind). Sweeps were taken 1.7 seconds apart. Details of the shape of the plume are clearly visible. Not shown are background-only sweeps prior-to and after the plume passage.

3.2.2.4 Meteorological Data

Weather data were collected by a variety of partners. The Canadian Joint Incident Response Unit (CJIRU) collected data using a weather station at base camp and radiosondes (the post-detonation radiosonde for shot 2 contained a Geiger-Muller tube for gamma-ray detection) released near ground zero before and after each shot. DRDC Ottawa collected 3D wind data using sonic anemometers at three heights, 20 m upwind of ground zero and additional data from a weather station placed between the base camp and the decontamination line. Health Canada collected weather station data near some of their perimeter monitors approximately 3-4 km downwind from ground zero. Table 1 shows nominal meteorological conditions for each of the three dispersions, based on 5 minute averages after each shot. Some of the meteorological instruments can be seen in Figure 6.

Figure 6: Meteorological instruments used to collect data during the RDD Field Trials. Left: Radiosonde used to collect vertical temperature and wind data. Centre: One of three sonic anemometers used to collect 3D wind speed data near ground zero. Right: Met station used to collect general weather data near base camp.

3.2.2.5 Air samples

The US Department of Energy (DOE) National Nuclear Security Administration (NNSA) provided air sampling measurements for the first two dispersions. The DOE Remote Sensing Laboratory (RSL) took multiple high-volume air samples during dispersions one and two. Personnel from the Pacific Northwest National Laboratory (PNNL) provided ultra-high volume air sampling for the first dispersion. The air samplers used can be seen in Figure 7.

RSL used Staplex high-volume samplers to take integrated air concentration measurements across the duration of the plume passage for these dispersions. The sampling rate was 35-40 CFM (approximately one cubic meter of air per minute), with aerosols deposited on four-inch paper filters. These samplers were placed at 19 locations for the first dispersion, and 12 locations for the second. Most measurements were taken at breathing height (1.5 m), but for both tests, two samples were taken at 10 m height to determine the vertical profile of the plume. Additional air

samples were taken after the dispersions to measure the resuspension. Detector details and preliminary results were presented in Las Vegas (see section C.2 number 20).

PNNL used gasoline and electric blowers as ultra-high-volume samplers to take far-field (600 m from GZ) integrated air concentration measurements across the duration of the plume passage for the first dispersion. The sampling rates were 875 (electric) and 1000 (gasoline) CFM, with aerosols deposited on large paper filters. These samplers were placed at 6 locations for the first dispersion, all at 600 m from GZ. Detector details and preliminary results were presented in Las Vegas (see section C.2 number 21).

Figure 7: Air samplers and their deployment. Left: PNNL ultra-high volume air-sampler (gasoline version). Centre: 10 m tower with RSL high volume air samplers at the top and bottom. Right: RSL high volume air sampler at breathing height (1.5m) on tripod.

3.2.2.6 RS-250 network

The RS-250 network consists of 3” × 3” NaI detectors designed to be operated in remote locations and set up quickly for sensitive area monitoring. Health Canada designed and built the system for emergency response, and deployed them during these trials. The system has been used in the past during Vancouver 2010, the G8/G20 summit and on the west coast following the Fukushima reactor releases. The detectors give high-sensitivity real-time dose rate information, and were used for monitoring both plume passage and ground deposition. The configuration and locations of these detectors can be seen in Figure 8. Figure 9 shows the dose rate changes from the passage of the plume in shot 2. Detector details and preliminary results were presented in Las Vegas (see section C.2 numbers 18, 25).

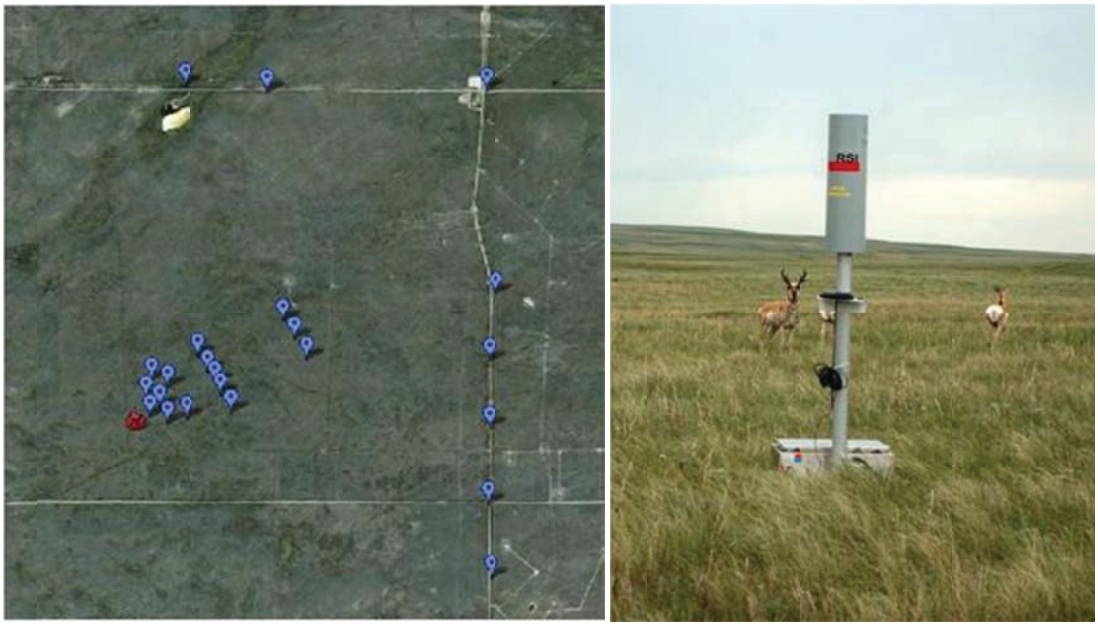

Figure 8: RS-250 detectors and their locations. Left: Locations for the RS-250 large volume gamma detectors. The blue pips denote the location of the detectors; the red marker is the position of ground zero. Right: One of the RS-250 detectors during set-up week.

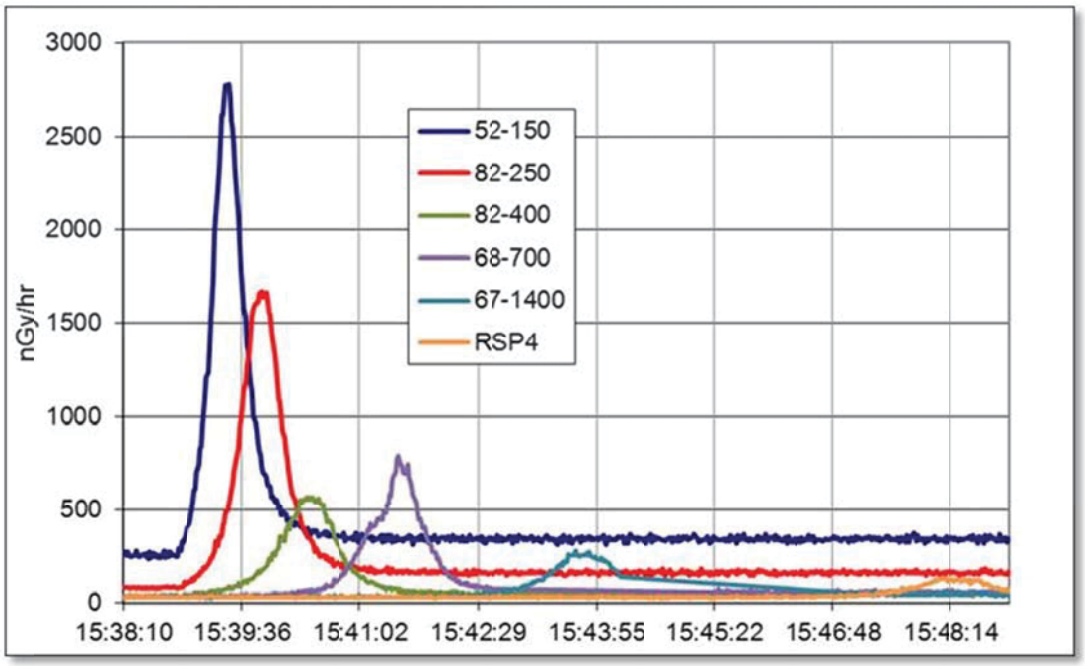

Figure 9: RS-250 data, showing the plume evolution for shot 2. Gamma dose rate with respect to time is shown for several detectors at varying distances from GZ. The initial dose rate is from the source in the device, pre-detonation, the spike is from the cloud-shine as the plume passes the detector and the residual dose rate is from the ground deposition. The x-axis is the time in Greenwich Mean Time (GMT). The shot took place at 9:38 Mountain Daylight Time (MDT)

3.2.2.7 RadEye PRD detection array

An array of 250 Thermo RadEye PRDs (Personal Radiation Detectors) was deployed to monitor the plume passage and deposition. A subset (10) of these detectors was shielded using sandbags in order to have a collimated vertical view to better determine plume passage times. The array was designed to maximize the chance of the plume passing over the most detectors, given the probable weather conditions. The PRD array can be seen in Figure 10. Detector details and preliminary results were presented in Las Vegas (see section C.2 numbers 19, 24).

Designing, assembling and deploying this array was a large team effort, led by DRDC Ottawa. Some of the major contributions were as follows:

- RadEye PRDs were provided by CBSA (>200) and DRDC Ottawa (60);
- Design and fabrication of a data-logger to communicate with the PRDs through the IR port and store/transmit data to a base station was done by ISR;
- Weather resistant stands for the detectors were designed and built by DRDC Ottawa;
- Testing of the PRDs and data-loggers was performed by ISR, RMC, and DRDC Ottawa;
- Preliminary array layout and staking of positions was performed by DRDC Suffield and DRDC Ottawa, with a detailed survey of locations later performed by NRCan;
- Assembly, deployment and disassembly of the units (stands, data-loggers, RadEyes) was done by everyone on site (primarily DRDC Ottawa, CJIRU, ISR, AWE, HC and CBSA); and,
- Data collection and remote monitoring and controlling of the units were done by ISR.

Figure 10: RadEye PRD detectors and stands. Left: PRD and data-logger inside weather-resistant enclosure. Centre: PRD stand showing closed box, base plate (which doubled as a witness plate for beta measurements), and external battery for the data-logger. Right: DRDC Ottawa personnel setting the detector array. Faceplates for the enclosures were colour coded corresponding to their angle in the array, to help the field teams orient themselves.

3.2.2.8 Airborne survey

NRCan provided airborne gamma dose rate mapping over the trial site for all three dispersions. The airborne system consists of two 4 litre NaI detectors mounted in a basket on the exterior of the helicopter with two additional crystals inside the helicopter. The detection system can be seen in Figure 11. Figure 12 shows the dose rate distribution over the trial site following the second dispersion. The helicopter flew at 40 m altitude for shots 1 and 2, and at 15 m altitude for shot 3. Surveys were performed as soon as possible, but no less than 30 min, after each shot. Detector details and preliminary results were presented in Las Vegas (see section C.2 numbers 23, 27).

Figure 11: The airborne detection system. The system consists of two 4 litre NaI detectors mounted in a basket external to the helicopter with two additional crystals inside the helicopter. The system logs dose rate, spectra and other information such as GPS location and altitude.

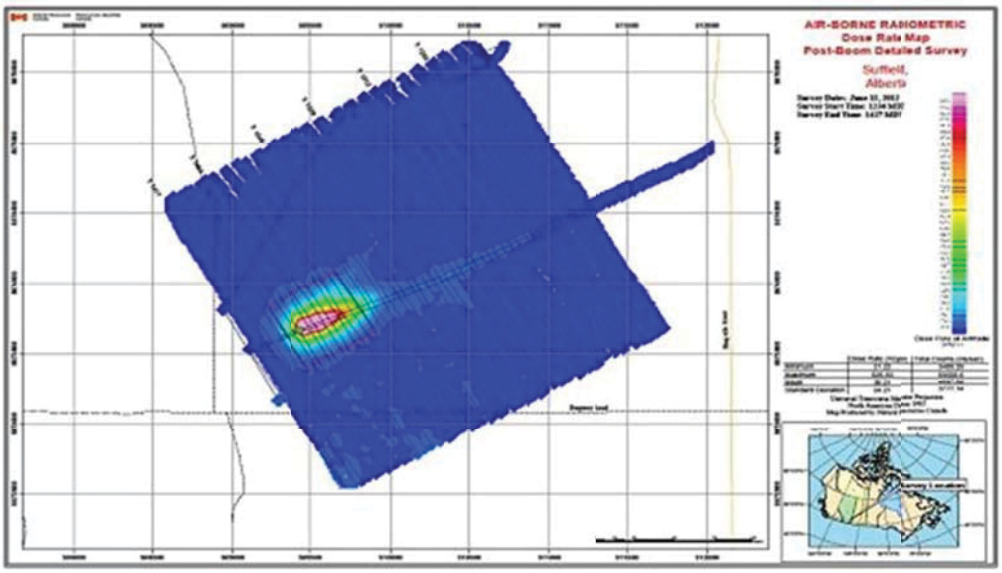

Figure 12: Airborne dose rate map from measurements following shot 2. Residual contamination can be seen from the first shot.

3.2.2.9 Ground-based gamma measurements

A number of ground based gamma measurements were taken in addition to the airborne measurements. Mobile, vehicle-borne measurements were taken by NRCan and by DRDC Suffield. NRCan used a high-volume directional gamma detection system mounted on the back of a truck (see Figure 13 for an example of the collected data). DRDC Suffield used 3” × 3” NaI detector, mounted on their MATS robot to map the plume direction. Both of these systems mapped the deposition in the warm zone, outside of the fence line. Fixed point *in situ* gamma measurements were also performed by both NRCan and RSL. NRCan used a NaI detector, while RSL used a portable HPGe system for these *in situ* measurements. Detector details and preliminary results from all of these measurements were presented in Las Vegas (see section C.2 numbers 26, 23).

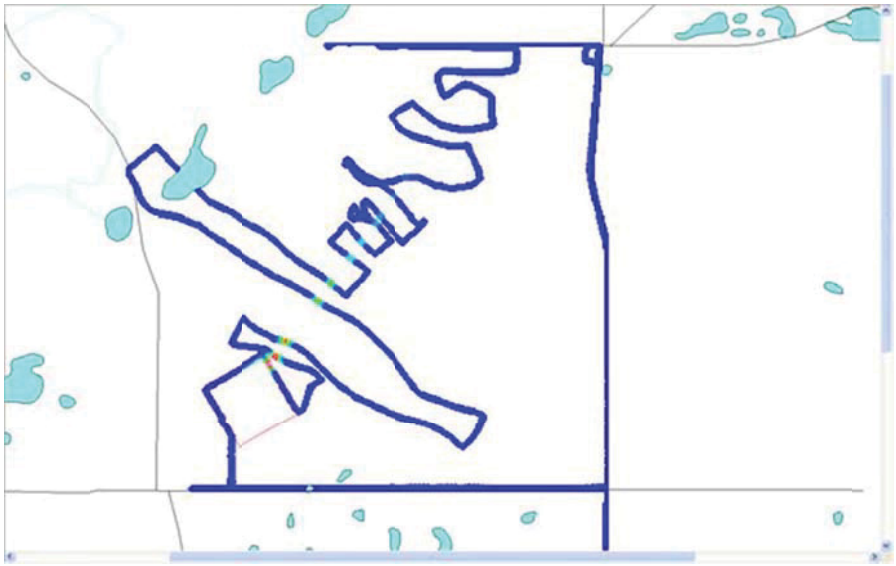

Figure 13: Example of data collected using the NRCan truckborne detection system. These data were taken following the first dispersion.

3.2.2.10 Beta measurements

DRDC Ottawa was responsible for collecting localized measurements of the lanthanum deposition, by measuring beta count rates on witness plates and other locations near ground zero and downwind. A pre-positioned array of 350 witness plates was used to collect deposition data for all shots. Each of the 250 RadEye support stands incorporated a witness plate into its base and an additional 100 plates were positioned near ground zero and between RadEye stands. Witness plate beta measurements were taken using Thermo RadEye AB100 detectors. Procedures were put in place to ensure that the beta team collected data not only from the witness plates, but also background measurements in the same area and measurements from standard check sources and common in-field plates to allow for subtraction of gamma cross-over and to identify instruments that were malfunctioning or contaminated. Figure 14 shows the AB100 probe, witness plate and a beta team collecting data in the field. An example of the data collected (from shot 1) is shown in Figure 15. Detector details and preliminary results from these measurements were presented in Las Vegas (see section C.2, number 22).

Figure 14: Beta probes and witness plates. Left: The Thermo AB100 probe and witness plate. Each probe was fitted with a jig that sits in alignment holes on the witness plate to allow reproducible placement and standoff. Right: One of the beta teams collecting data in the field.

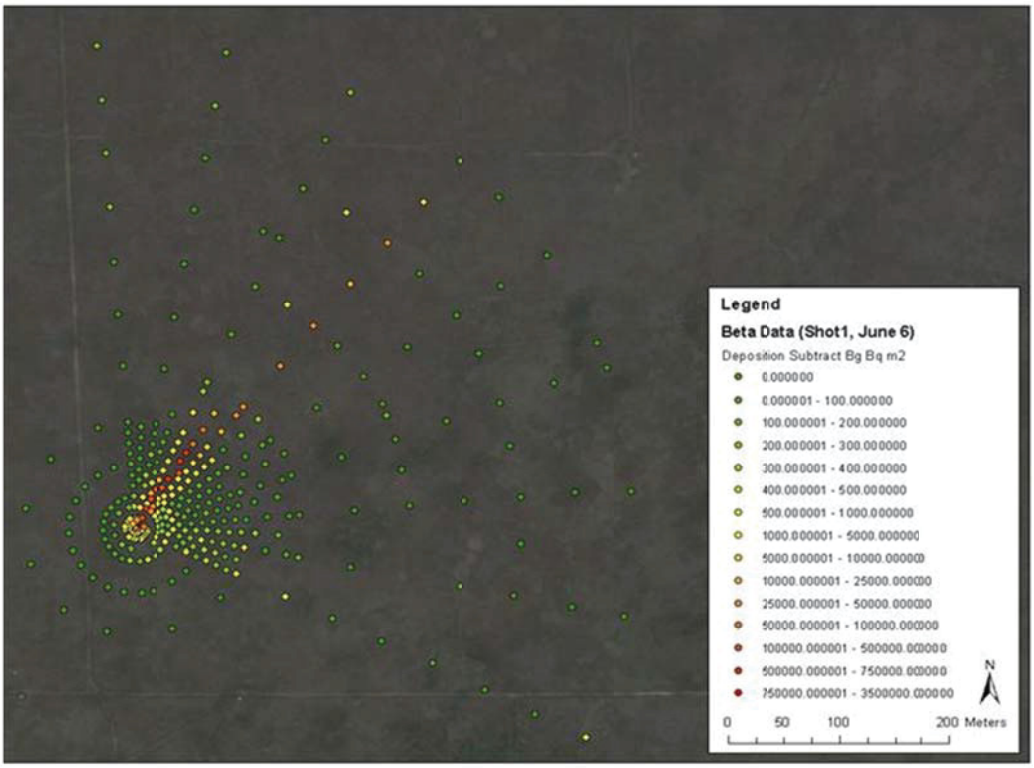

Figure 15: Preliminary beta deposition data from shot 1.

DRDC Ottawa performed additional measurements at ground zero and along the width of the plume using a different instrument following dispersion 3. The Bruker SVG-2 was used for this as it has excellent beta/gamma discrimination and works better in highly contaminated areas. The SVG-2 was compared to the AB-100 at witness plate locations to obtain as estimate of its overall efficiency, and then was used to map the highly contaminated area at ground zero. Figure 16 shows the mapped pattern of the highly contaminated area at ground zero. This type of detailed mapping is only possible using beta measurements, and provides invaluable insight into the localized threat at ground zero following an RDD Event.

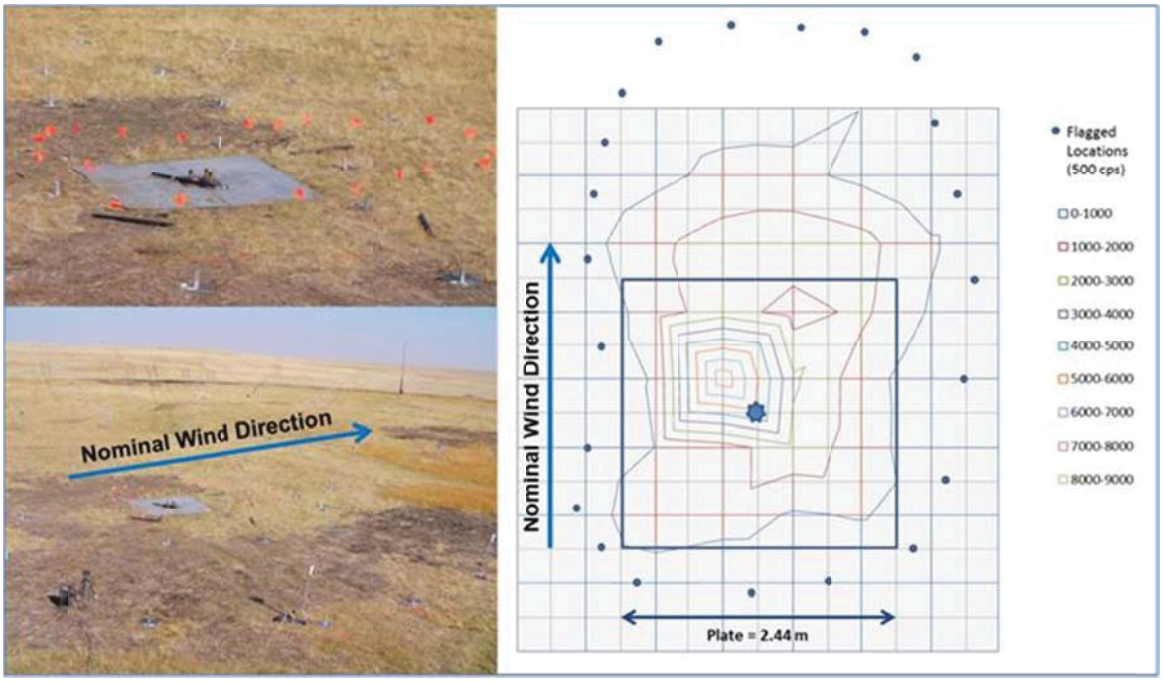

Figure 16: Beta contour plot around ground zero for shot 3. The blue star marks ground zero, the blue square represents the metal base plate seen in the photos. The blue dots represent the flagged locations from the photos, which demark the edge of the highly contaminated area.

3.2.2.11 Additional measurements

In addition to the above mentioned measurements, there are a few other collected data types worth noting here. Health Canada placed large (approximately one square meter area) deposition filters at a number of locations downwind (co-located with their RS-250 detectors). These filters passively collected the dispersed radioactive particles as they deposited through gravity and wind action (not with air samplers). The deposition filters were packaged and shipped back to the Radiation Protection Bureau in Ottawa to be counted on a high sensitivity HPGe detector and imaged using autoradiography. Examples of autoradiography images from shot 1 are shown in Figure 17. Additional information about the fireball dynamics and cloud rise were taken from measurements of still frames from high speed and regular speed videos of each of the shots. Stills from the high speed video from shot 1 are shown in Figure 18.

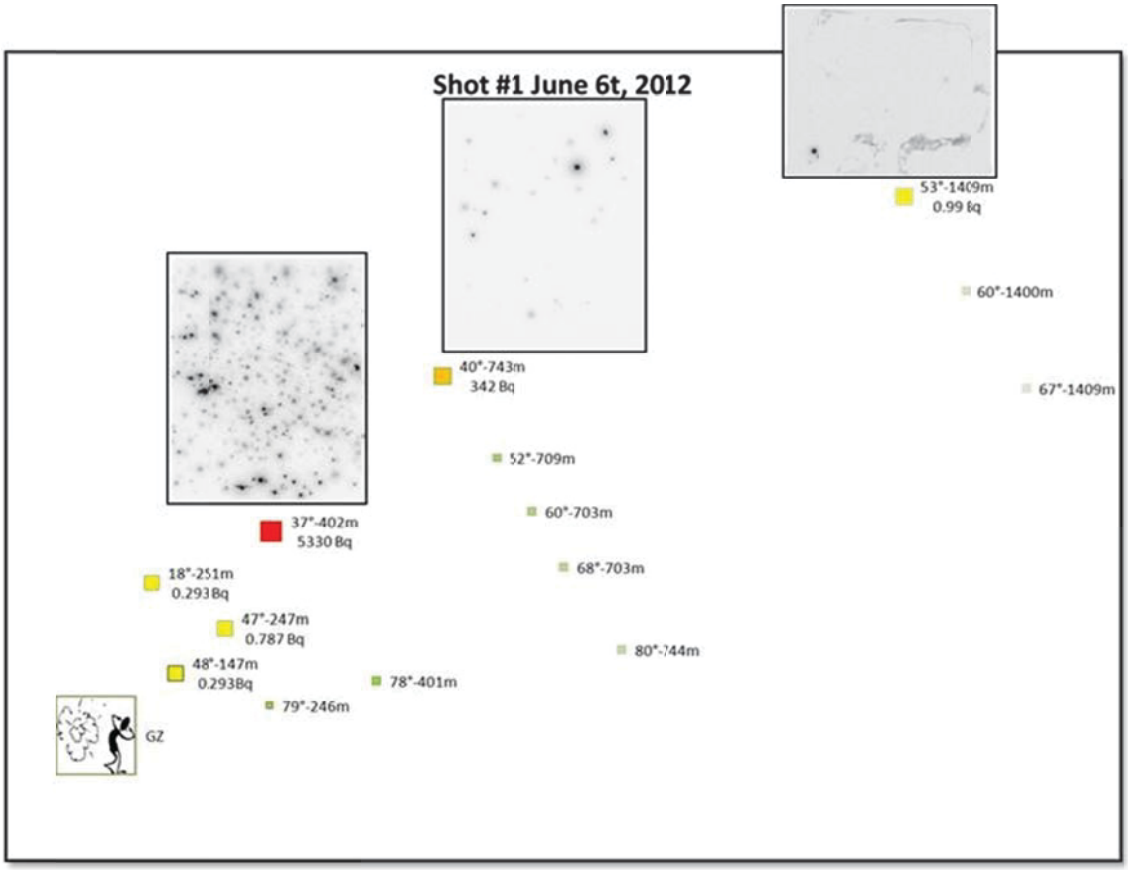

Figure 17: Autoradiography images of passive deposition filters collected after shot 1. Each dot on the image represents a radioactive particle deposited on the filter, with the colour of the dot corresponding to the total activity on the filter. Green dots had no measurable activity on the filter, activities from HPGe measurements are given for the other filters.

Figure 18: Still frames from high speed video before and after shot 1. The post-detonation still shows the fireball at approximately its maximum size, but before it has quenched. Hot aerosol particles in the stem at the top of the fireball are starting to cool.

3.3 Modelling results

The bulk of the modelling effort undertaken by the DRDC Ottawa Synthetic Environments Group (and later under subcontract from International Safety Research to the SimuTech Group, Inc.) involved stitching together relevant codes that operated on different distance and time scales, and validating that the carried-over results were physically correct (see section 2.3). The best codes found to build on were AUTODYN and CFX.

- AUTODYN is an explicit dynamics code which specializes in high speed events (< 10^{-4} s duration). It is ideally suited for the simulation of the explosive blasts to capture the energy released and the initial momentum transferred to the surrounding material.
- CFX is a Computational Fluid Dynamics software intended to simulate fluid flow in a variety of situations. In this case, we are using it to perform the transient analysis of compressive gasses to capture the shock waves and material mixing in the post-detonation fireball.

The two have been successfully merged in that energy and momentum have been shown to be conserved between the two sets of code (i.e. no critical information is lost when we move from one time/size regime to the next.) Figure 19 shows the output of AUTODYN becoming the input of CFX. This was not easily done, as the mesh size was different for each program. A combination of meshed (for functionality) and mesh-less (for precision) schemes had to be developed and employed [12].

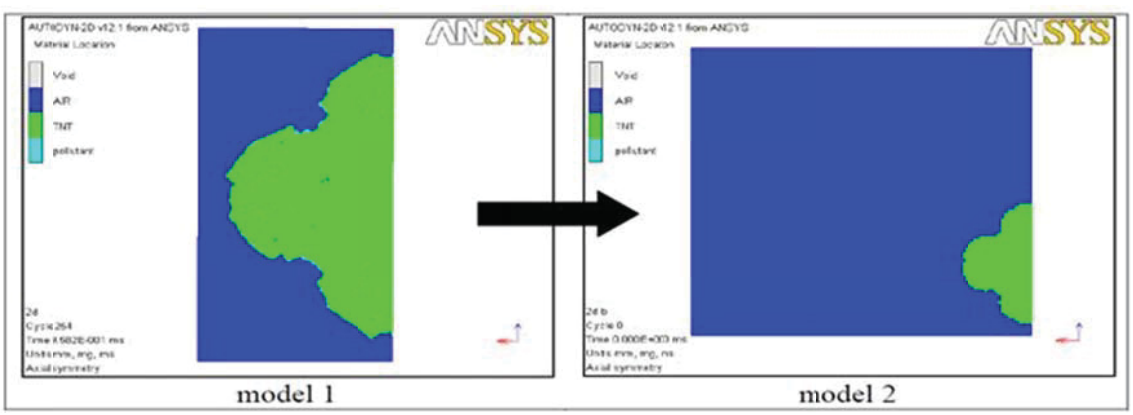

Figure 19: Output of AUTODYN becomes the input for CFX. Model 2 is in a form that can be ported to CFX. Extensive modifications needed to be made to the codes themselves as well as the input/output files used by each.

The combined output of AUTODYN and CFX can, in turn, be combined with any number of atmospheric dispersion codes. The results from the combination of AUTODYN and CFX have been shared with our international partners.

Additional modelling work was performed by AWE using an in-house explicit dynamics code with similar to functionality to AUTODYN. This modeling effort resulted in an equation of state

for the lanthanum oxide material dispersed in the trials and used it to examine the early dynamics of the explosive detonation, and its effect on the particle dynamics. The AWE modelling results are currently being compared to the flash x-ray images taken at DRDC Valcartier during the detonation of the actual device. The results of those studies were presented at the US/UK/Canada Conference in a classified briefing. Detailed final results will be published in classified AWE and DRDC Valcartier reports.

3.4 New capabilities, partnerships and networks

As a direct result of this project, Canada and its allies have a better understanding of RDD events, and better tools to predict consequences and plan for response. In addition, a number of new capabilities and partnerships were developed as the project team encountered and overcame the many challenges associated with planning and executing the trials, and processing the resulting data to create a common and consistent data set for each event. These will be briefly reviewed in the following sections.

3.4.1 Capabilities

The RDD field trials represent the sole occasions upon which Canadian federal field teams have deployed into a large-scale, contaminated, outdoor environment to characterize unknown deposition patterns. Canada's field capabilities for nuclear emergency response have, therefore, been enhanced enormously by this experience.

3.4.1.1 Response planning and hazard assessment

The project has achieved its stated objective of contributing to improvements in modelling tools for RDDs, thereby improving capabilities to make realistic predictions about potential hazards and plan and execute an appropriate emergency response. The data generated through the experimental trials will inform model development and interpretation in Canada and abroad, including atmospheric transport models that support Canadian nuclear emergency preparedness and radiological consequence management under the Federal Nuclear Emergency Plan (FNEP).

3.4.1.2 Joint response capabilities and hot zone operations

The trials provided unprecedented opportunities for Canada's federal radiological response community to carry out real work in a large-scale, contaminated outdoor environment, similar to what they would expect following an unplanned radiological dispersal event. Despite extensive planning and preparation going into the spring trial, there were a lot of uncertainties and unknowns. Protocols had been drafted for the Experimental Plan but, for the most part, had never been used in the field and/or with dispersed radioactive material.

At least 35 personnel representing all 6 organizations from the Federal Radiological Assessment Team rotated through the hot zone over the course of the two trials, along with field specialists from the Canadian Joint Incident Response Unit (CJIRU). Over the course of the two trials, the assembled personnel learned about each other's capabilities and improved upon their own. Comfort levels between former strangers increased as people demonstrated their skills and

improved them through feedback. Improvements in data collection techniques, decontamination and access control protocols, and health & safety strategies were significant. Federal readiness for technical field response under FNEP or in support of the National CBRNE Team is likely at an all-time high as a result of the RDD trials last year.

3.4.1.3 Data analysis and amalgamation

Table 2 identifies 14 different categories of radiation data measurements that were collected for this trial, representing different instruments at different distances from the source, with different sampling frequencies and reported in different units. While most of this equipment is part of Canada's federal inventory that would be deployed during a nuclear emergency, only limited consideration has been given to how measurements would be compared to identify anomalies and generate a common and consistent picture of contamination in an area.

The requirement to produce a high quality data set for model validation has highlighted this issue for the project team. Novel methods for unfolding aerial survey data to increase the precision of ground-level concentration plots are in development at NRCan and will facilitate inter-comparisons between deposition data sets. Better understanding of how different data sets compare is an important first step in closing this capability gap.

3.4.1.4 Other capabilities

A number of other capabilities were developed during the trial. These include

- New techniques for measuring temperature within the explosive fireball;
- Equipment and procedures to improve the "fine motor skills" of the robot used to load the radioactive source in the explosive device;
- Equipment and procedures to collect beta data without contaminating the instrument;
- Guidance for conducting future explosive radiological dispersals for experiments, training, and equipment testing. This will be a leave-behind for the CTTC and other organizations wanting to carry out similar experiments, and is also mentioned in Section 4, Transition to End Users.

3.4.2 Partnerships and networks

The project team grew from 9 organizations in the original project charter to 16 in the field in Suffield, all of whom were put to work and many of whom travelled at their own expense. The project benefitted enormously from interdepartmental and international cooperation which, in turn, has resulted in significant improvements in the readiness and cohesion of radiological and explosives assets and expertise in Canada and the US.

3.4.2.1 Foreign investment

In-kind contributions from US DOE and UK (AWE) partners were critical to the success of this project. In addition to access to data and subject matter expertise that was initially forecast in the

project plan, these organizations went above and beyond by generously providing practical support prior to, during, and after the trials. Ongoing collaboration is planned to refine the data set and publish the results.

Specific examples of US and UK contributions include the following:

- Collaboration on explosive device design (SNL and Valcartier)
- Participation in international RDD workshops hosted at Sandia National Laboratories
- Indoor explosives trials to characterize post-blast particle size distribution (SNL, who stepped up when DRDC Valcartier unexpectedly lost access to their facility)
- Modelling expertise, especially following the loss of DRDC Ottawa modelling resources (AWE)
- Advice, equipment, and personnel for planning and executing the trial (RSL attended the Dry Run in May 2011; RSL and PNNL conducted air sampling at the Spring Trials; and AWE sent people to observe and help out at both the spring and fall trials). All international participants bore all of their own costs.
- Support to post-trial data analysis and sharing through meetings (RSL hosted a week-long workshop in February 2013) and commitment to joint publications

3.4.2.2 Canadian investment

Project partners have all contributed significant time, resources, and expertise to this project. Most will continue to work with the data and publish well after the official project end date.

The project was able to leverage previous investments (CRTI and otherwise) in equipment and specialized facilities through project partners. This helped control project costs while simultaneously improving interoperability and awareness of partners' capabilities.

When project partners did not have all of the required capabilities, the team was able to recruit expert support from other federal radiological response organizations, including AECL, CJIRU, and DRDC CSS. For the most part, these organizations covered their own costs, which have been included as in-kind contributions.

Canadian in-kind contributions in the following areas were particularly valuable:

- Contamination control and the decontamination line: leadership, expertise, personnel, and supplies (CJIRU sent two decontamination specialists to the first trial and one to the second; AECL sent several to both trials and provided instruments and PPE for the second)
- Meteorological support: on-site data collection and supplies (CJIRU); local weather forecasts (EC CMC)
- Detectors for the datalogger array: access to more than 200 RadEye PRDs for the duration of the trials (CBSA)
- Site set-up, infrastructure, and logistical support: years of experience in military logistics and conducting field trials were brought to bear to erect the temporary facilities and instrument

array that became the Dugway Site, and to meet the myriad demands of the trial teams (DRDC Suffield).

3.5 Lessons learned

One of the smartest actions of the project team was to surround themselves with experts in the various domains required to deliver this project, particularly when organizing the field trials. While the same approach was initially adopted for the modelling stream, these experts were lost and not replaced, and those aspects of the project never fully recovered.

Issues were encountered almost daily and the project team was routinely forced to adapt to unexpected circumstances and requirements. Regular communication, including bi-weekly teleconferences with project partners, helped to keep the project on target and moving forward. Several other lessons learned have already been mentioned in this report; others will be implemented through improvements to protocols and operating procedures, as well as through publications and presentations at internal and open meetings, conferences and journals.

A number of practical and safety-related lessons learned were identified during the course of the conduct of the field trials. These are not reproduced in this document, but can be found in the Field Trial after Action Report [7].

4 Transition and exploitation

This project represents a significant investment from all the partners and participants who provided time, expertise and effort and from DRDC Centre for Security Science, who provided the funding. The project was extremely successful in that it was able to generate a wealth of unique real-world data on the dispersal of radioactive material from an RDD; however, real success in this context cannot come from mere data generation. True success must include a reduction in the risks involved with RDDs, making Canada and our allies better able to prevent or respond to an RDD attack. In order to do this, the data must be transitioned to the RN risk modeling and emergency response communities to allow them to improve effects models, response procedures, detection equipment and expertise amongst responders.

4.1 Transition to end users:

The main leave-behind at the completion of this project is the wealth of data that were collected during the three dispersion field trials (described in section 3.2.2). There are additional experimental data that were generated prior to the field trials (see section 3.2.1) that set the context for interpreting the field trial results. Additionally, the knowledge of how to safely conduct trials of this nature is extremely valuable for any potential future studies of this kind. This project does not have the scope and funding to take in all data analysis activities, and so it is expected that these data will be used by dispersion modellers and other researchers for model validation and other studies for years to come. This section describes the project team's approach to ensure that this transition occurs.

4.1.1 Database development

To facilitate data sharing and potential future studies with these data, Health Canada has put in a great deal of effort to transition all collected data from the trials (and the lead-up to the trials) into a properly structured and annotated database. This database, along with individually cleaned and vetted data files, will allow the data to be shared with end-users in a self-explanatory way. This database has been structured in such a way that the majority of it can be easily ported into the US RAMS database system that is used operationally for radiological emergency response. The details of the structure of the database were briefed at the US/UK/Canada Conference on RDD Field Trials (see section C.2 number 28) and will be published as a Health Canada report.

4.1.2 Publishing strategy

Publishing studies in the open literature is the best way to ensure that the results of experimental work are shared to a wide audience and recorded for future reference. This project plans to publish most of its results in the open literature. Where there is sensitive, controlled or classified information, internal DRDC or other project partner reports will be utilized with the appropriate markings and controls in place. An example of classified information in this project is in the details of the design of the explosive device used to disperse the radioactive material. This information has been classified as SECRET and will be published at that level by DRDC

Valcartier and UK AWE. All published information will be vetted for controlled goods and classification.

Open literature publications will be prepared for a number of different journals, depending on the exact topic of the paper. Of particular note, the Health Physics Society (HPS) have agreed to hold a special session at the 2014 HPS Annual General Meeting to highlight the results of this project. Following the HPS Meeting, a special edition of the Journal of the Health Physics Society will be published featuring papers from this project and potentially from other similar trials.

Other relevant conferences and journals include:

- IEEE Nuclear Science Symposium,
- Nuclear Instruments and Methods,
- Journal of Environmental Radioactivity,
- Journal of Applied Radiation Isotopes.

4.1.3 Engaging the modelling community

The main end-users for our dataset are the modelling community who specialize in atmospheric dispersion modelling, including urban dispersion codes. A number of these communities have already been engaged in the project as partners (Environment Canada, Health Canada, UK AWE, ISR). Others are starting to be brought in through presentations at working meetings and international workshops on RDD Characterization and through community development initiatives within the Canadian Federal RN Community. Some examples of this include the following:

- The US National Atmospheric Release Advisory Centre attended the UK/US/Canada Conference on RDD Field Trials. They presented preliminary modelling results from their high fidelity dispersion models, and are refining their models based on field trial data. They develop and maintain a number of both simple and sophisticated dispersion codes used extensively in the US and worldwide.
- Atomic Energy of Canada Limited is leading a CSS community development study to compare RDD dispersion codes among the various Canadian federal departments who have that capability. This includes a code being adapted for RDD modelling at AECL and operational codes used at Environment Canada's Canadian Meteorological Centre and at Health Canada's Radiation Protection Bureau. Data from this project will be used for model validation and cross-comparison.
- Details of the project, including results of the field trials, will be briefed at the upcoming 2013 RDD Workshop. This workshop is being hosted by Sandia National Laboratories in Albuquerque NM in October 2013. Participants at this workshop include most of the experts in RDD characterization, risk assessment and modelling from the US, UK, Canada and Australia and is held at the SECRET level. This meeting is key to engaging the experts in this field, and ensuring that our data are utilized within this community.

4.1.4 Lessons for emergency planners and responders

Beyond the dispersion modelling communities and RDD subject matter experts, there are other communities that are end users for these data. These include emergency planners who rely on validated risk assessments to develop response plans and emergency responders who rely on the scientific and modelling community to provide sound advice for development of their response procedures.

Many of the partners on this project are intimately involved in the Canadian federal government emergency planning process and would be called upon to respond in the event of an RDD attack in Canada. This has some key benefits for emergency planners and responders in Canada:

- All of the federal departments involved have input into the CSS Consolidated Risk Assessment process. The results of these trials will inform that process greatly in future years.
- Health Canada is in charge of the Federal Nuclear Emergency Plan (FNEP) which also draws expertise from many of the project partners in the event of a radiological emergency. The experience on this project will help HC refine the plans in FNEP and provide better informed responders if the plan needs to be activated.
- DRDC Ottawa developed the Probabilistic Risk Assessment Tool (PRA Tool) for RDDs. These trials will help validate the inputs to this software tool.
- Lessons learned from these trials have already been incorporated into the "Advanced RN Response Course" which DRDC Ottawa and DND's Director of Nuclear Safety provide to CJIRU on an annual basis. This course is also attended by members of the RCMP, ensuring that the National CBRN Response Team is trained with the latest scientific knowledge on RDD risks and phenomena.

4.1.5 Maintaining RDD field trial capabilities

The collection of safety manuals, operational plans, regulatory documents, dose histories, detection/monitoring techniques, and all other field procedures from these trials form what is virtually a how-to manual for the conduct of similar field trials in the future. This capability is currently unique in Canada and amongst our allies in the US, UK and Australia[2]. Maintaining the ability to perform similar RDD field trials in the future opens up many possibilities for unique and valuable studies. This could support activities such as detector development, trials of response protocols, operational testing of equipment in a realistic environment, training and many other potential uses. To help maintain this capability, we are planning to write a summary document on conduct of the field trials, including lessons learned and all documentation prepared in advance of the trials.

[2] Similar experiments have been performed recently in Israel, but on a smaller scale, using technicium-99m.

4.2 Follow-on commercial development

As mentioned above, the main outcome of this project was the wealth of unique data that it generated regarding real-world RDD effects; however, there are two areas of note where intellectual property was developed that can be exploited commercially.

- ISR is continuing to support the Data-Loggers that were developed for this project. They are continuing to invest R&D funds to improve the devices based on the lessons learned during their deployment in Suffield.
- SimuTech has incorporated the AUTODYN to CFX capability, allowing meshed and meshless transitions. Without further funding, SimuTech will not be modifying their code further.

4.3 Intellectual property disposition

The IP shall continue to follow the standard recorded in the Project Charter [13], reproduced below.

4.3.1 Background IP and new IP

Each project participant shall retain all right, title, and interest in and to all inventions, improvements, or discoveries that were conceived or made

- prior to the commencement of the project solely by one or more employees of that participant ("Background IP");
- during the performance of the project in collaboration with project partners, if such improvements/modifications were made to an existing proprietary system;
- during the performance of the project solely by one or more employees of that participant ("New IP").

4.3.2 Joint IP

The parties whose employees have jointly conceived or made an invention, improvement or discovery during the performance of the project shall jointly own all right, title and interest in and to such inventions, improvements, or discoveries ("Joint IP"), except where such i*s applied to existing proprietary material.*

4.3.3 Grant of rights

Each project participant grants the Crown a non-exclusive, royalty free right to use the Background IP, New IP and Joint IP for research related to the project for the duration of the project, but not for commercial, purposes. This includes all project participants to the level of subcontractors.

4.4 Public information recommendations

Some of the information generated by this project is classified (explosive design), but the majority should be releasable to the public. In section 4.1.2 the publication strategy is outlined for open literature publications. Beyond scientific articles, it may be prudent to prepare a few popular science articles for relevant publications. These could include internal newsletters such as DRDC's Leo Online, DCBRND's Dragon's Din, The Maple Leaf, CBRNe World, etc. Media response lines were prepared prior to the trials, and these could form the start of some of these articles. Any article like this should emphasise emergency preparedness, collaboration among federal partners and how this research leaves Canada better able to respond to radiological emergencies.

5 Conclusions

Project 07-0103RD "Full-Scale Radiological Dispersal Device Experiments and Models" was funded by the DRDC Centre for Security Science in order to better characterize the real-world effects of radiological dispersal devices and to allow Canada to be better prepared to respond to them. This project, led by DRDC Ottawa, spanned five years and involved a total of 18 different organizations, 9 of which were official project partners.

The project involved both an experimental stream and a modelling stream. The modelling stream investigated how best to stitch together physics models relevant to the different time and distance scales involved in an RDD, with the ultimate goal being a seamless model that could predict RDD behaviour from start to finish. The experimental stream involved a series of experiments with inert (non-radioactive) material that were designed to characterize the explosive dispersal device that was later used in full-scale outdoor dispersal experiments using ^{140}La as a short-lived radioactive tracer.

The modelling stream suffered a reduction in scope due to shifting priorities and loss of key personnel at DRDC Ottawa, but did result in a method for taking the output of an AUTODYNE hydrocode simulation and using that as an input to the computational fluid dynamics code CFX while conserving energy and momentum. The outputs of the modelling stream have been transferred to international partners and to industry for exploitation, rather than forming the basis for a Centre of Excellence at DRDC Ottawa, as initially envisioned at the outset of the project.

The experimental stream was successful beyond initial expectations. The source term and explosive device characteristics were measured in a series of preliminary experiments using inert material. The culmination of the experimental stream was a series of three explosive dispersal experiments that were carried out in the spring and fall of 2012 on the DRDC Suffield Experimental Proving Grounds. These trials resulted in an extensive dataset from a wide variety of instruments and detection systems. These systems measured the real-time passage of the plume, the deposition on the ground, and the meteorological conditions of the trials in great detail. The measurements collected form a unique set of data from an outdoor radioactive dispersal, spanning all distance and time scales of an RDD event from the explosive shock wave travelling through the material to the plume formation and evolution to deposition. Analyses of these data sets are expected to take months to years to complete.

As a result of this project Canada and its allies have a better understanding of RDD events and enhanced capabilities in consequence prediction and response planning. These enhanced capabilities include better modelling tools, procedures for working in large-scale contaminated environments, methods for joint response and tools for collecting and interpreting field data from a variety of operational detection systems. Although the project has reached the end of its timeline according to the charter, work will continue. The focus in the coming months to years is to publish results as a mix of open literature and internal documents to ensure that end-users of these results are engaged and aware and to maintain our capability to perform similar field experimental work in the future.

References

[1] DRDC Centre for Security Science (2010), Chemical, Biological, Radiological/Nuclear and Explosive (CBRNE): Consolidated Risk Assessment (S) (DRDC CSS R 2010-01) Defence R&D Canada – CSS.

[2] Harper, F.T. and Rhodes III, W.G. (2004), A Realistic Assessment of Potential Effects from Radiological Dispersal Devices (UCNI) (SAND 2004-4368) Sandia National Laboratories.

[3] Harper, F.T., Kipp, M.E., Johnson, P.N., Boughton, B.A. and Graeber, E. (2004) Experimental Characterization of Explosively Generated Aerosol from Metallic Shells in Implosion Geometries (UCNI) (SAND 2004-4195) Sandia National Laboratories.

[4] Musolino, S.V. and Harper, F.T. (2006) Emergency Response Guidance for the First 48 Hours after the Outdoor Detonation of an Explosive Radiological Dispersal Device, *Health Physics,* 90(4), 377-385.

[5] Green, A.R. (2012) CRTI 07-103 RD Trials, ONTAP-0002-12 (DRDC Suffield Online Turbo Approval Process), 4 May 2012.

[6] Erhardt, L.S., Quayle, D., Green, A.R., White, D., Noel, S., *et al.* (2012) Full-Scale Radiation Dispersion Device Experiment Plan Version 2.8.

[7] Erhardt, L.S., Quayle, D., Green, A.R. and White, D. (2012) After Action Report: Full-Scale RDD Spring Trial.

[8] Erhardt, L.S., *et al*., (2008) CBRNE Research and Technology Initiative (CRTI) Full Proposal Application 07-0103RD: Full-Scale RDD Experiments and Models

[9] Erhardt, L.S. *et al.* (2012) Radiological Practice Approval Form CRTI-07-0103RD (RadPAF 2011-004) Defence R&D Canada – Suffield. 13 Feb 2012.

[10] Lebel, L.S. (2012) Aerosolization and Soil Entrainment in Explosive Fireballs, *Royal Military College Ph.D. Thesis*, October 2012. 242 pages.

[11] Cao, X. (2013) Report on RDD Lidar Measurements at Suffield (DRDC Valcartier TR IOSL TR 2013-0001) Defence R&D Canada – Valcartier.

[12] Rapoliti, N. (2012) Phase III Modeling Results – AUTODYN to CFX Mapping Code, ISR Sub-contractor report from SimuTech, July 2012.

[13] Erhardt, L.S. *et al.* (2011) Project Charter CRTI-07-0103RD "Full-Scale RDD Experiments and Models" Version 4.0.

This page intentionally left blank.

Annex A Project team

Position	Name	Org.	Phone	E-Mail Address
Project Role				
Project Champion	Mr. Paul Pulsifer	DRDC Ottawa	613-998-2569	Paul.Pulsifer@drdc-rddc.gc.ca
Project Manager	Dr. Lorne Erhardt	DRDC Ottawa	613-991-5900	Lorne.Erhardt@drdc-rddc.gc.ca
Portfolio Manager	Mr. Ian Summerell	CSSP	613-943-2504	Ian.summerell@drdc-rddc.gc.ca
Assistant Project Manager	Ms. Debora Quayle	HC	613-853-9515	Debora.Quayle@hc-sc.gc.ca
Deputy PM: Project Management	Mr. Mike McCall	ISR	613-241-4884	McCall@i-s-r.ca
Deputy PM: Indoor Experiments	Mr. Patrick Brousseau	DRDC Valcartier	418-844-4000 x4274	Patrick.Brousseau@drdc-rddc.gc.ca
Deputy PM: Outdoor Experiments	Dr. Anna Rae Green	DRDC Suffield	403-544-4011 x5478	AnnaRae.Green@Drdc-rddc.gc.ca
Partner	Dr. Laurel Sinclair	NRCan	613-947-3337	lsinclai@nrcan-rncan.gc.ca
Partner	Mr. Pierre Bourgouin	Environment Canada	514-421-4614	Pierre.Bourgouin@ec.gc.ca
Partner	Dr. William Andrews	RMC	613-541-6000 x6052	andrews-w@rmc.ca
Partner	Mr. Grant Gallant	CBSA	613-941-8552	Grant.Gallant@cbsa-asfc.gc.ca
Project Participants				
Scientific Advisor	Dr. Fred Harper	US Sandia Labs	505-844-1886	ftharpe@sandia.gov
Scientific Advisor	Dr. John Shaw	UK AWE	(+44) 118 985 5170	John.Shaw@awe.co.uk
Scientific Advisor	Dr. Dan Blumenthal	US DoE	202-287-5269	Daniel.Blumenthal@nnsa.doe.gov

Annex B Project performance summary

This annex evaluates the performance of the project against the initial goals laid out in the full proposal and the first version of the Project Charter. There were changes to the project schedule and scope that occurred over the course of project delivery; these were discussed and approved at project review committee meetings, and have been noted in the main body of this completion report. Subsequent versions of the Project Charter reflect these changes. Again, what follows here is a summary of the project performance as compared to the initial vision for the project with any significant deviations noted.

B.1 Technical performance summary

This performance summary compares the technical goals as laid out in the project proposal to the actual achievements of the project.

B.1.1 Field trials and data collection

The quality and quantity of data collected exceeded the expectations at the onset of this project. A significant amount of data was collected from real-time detection systems allowing characterization of the cloudshine from the plume passage. Additionally, the US DOE contributed a significant amount of unanticipated in-kind effort to the project, providing high volume near- and far-field air sampling.

B.1.2 Agent based modelling

Agent-based modelling had to be dropped from the project (with all approvals obtained during PRC 2010-2011), due to irreconcilable differences regarding IP requirements between the US and Canada.

B.1.3 Physics Modelling

Significant success has been achieved meshing the output of the hydrodynamic code used to model the fireball with dispersion codes used to track the particles (SimuTech Group Inc.). Further advances were made by AWE in modelling the source term generated by the trial device using their hydrocode and incorporating the physical data from the real-world trials into HPAC and DIFFAL. This work and other work by Environment Canada, Sandia National Laboratories, NARAC, AWE and ISR is continuing beyond the nominal end of this project.

B.2 Technology Readiness Level of deliverable (TRL)

The main leave-behind at the completion of this project is the wealth of data that were collected during the three dispersion field trials (described in section 3.2.2). There are additional experimental data that were generated prior to the field trials (see section 3.2.1) that set the context for interpreting the field trial results. This dataset is unique and is not measurable on the

TRL scale, more applicable to hardware. In the project proposal two more concrete leave-behinds were identified.

B.2.1 Training

The collection of safety manuals, operational plans, regulatory documents, dose histories, detection/monitoring techniques, and all other field procedures form what is virtually a how-to manual for the conduct of similar field trials in the future. This capability is currently unique in Canada and amongst our allies in the US, UK and Australia. Maintaining the ability to perform similar RDD field trials in the future opens up many possibilities for potentially valuable studies. To help maintain this, we will write a summary document on conduct of the field trials, including lessons learned and all documentation prepared in advance of the trials. There are no plans at present to turn this into a training package, but the capability will be maintained to support future activities such as detector development, trials of response protocols, operational testing of equipment in a realistic environment, and many other potential uses including training, if that is required in the future.

B.2.2 Centre of excellence

The idea of a modelling COE at DRDC Ottawa was dropped due to shifting DRDC priorities and loss of personnel. This is partially achieved through a wide reach-back capability rather than a single "center".

B.3 Schedule performance summary

As expected for a five-year R&D project there were unexpected delays that occurred intermittently throughout the life of the project. Table 3 compares the initial Project Schedule (from the first project Charter) with the final schedule of actual events. A brief summary of the delays and their effects are listed below.

B.3.1 Contracting issues

Initial contracting delays through PWGSC for both a United States based software company (NECSI Inc.) and an Ottawa based company (ISR Inc) had lasting repercussions. The contract with NECSI was never signed due to issues of IP and divergent international requirements. As a direct result, the two initially planned modelling streams were combined. A portion of the combined modelling was shifted to a sub-contractor of ISR (SimuTech Group Inc.), further delaying the contract with them. The contracting delay with ISR was initially dealt with through the use of a standing offer between ISR and the Department of National Defence (DND). This arrangement expired, but the PWGSC contract was in place by that time.

B.3.2 Loss of licence and fire damage

At DRDC Valcartier, there were delays in the renewal of an explosives licence. The renewal process was lengthy and shifted several milestones to the right. Additionally, the loss of the

LIDAR van in a fire compounded delays in achieving the early results from Valcartier that were to inform several subsequent steps in the experimental process (explosive selection, device design and indoor aerosolization experiments). Sandia National Labs in the US stepped up and assisted with device work until the facility at Valcartier was running.

B.3.3 Loss of key personnel

Following reorganization within DRDC Ottawa, the two scientists who were working on the modelling effort were lost. After the loss of the first scientist, modelling work was shifted to a private company (SimuTech Group Inc.). This work was handled through ISR, a full project partner, but one that is reimbursed through the PWGSC contract. Amending the contract to include a large portion of the modelling work necessitated several more months of delay. The loss of the second modelling scientist did not actually cause more delays, but rather lead to the transfer of modelling from project partners to participants external to the project. Loss of these personnel contributed to the decision to drop the modelling COE from the project plan and the shift of modelling responsibilities to international partners.

B.3.4 V2010 Olympic Games

Experimental preparations had to be significantly reduced (and in some cases temporarily suspended) while project partners prepared for the 2010 Olympic Games. This preparation included training security forces, deploying equipment, readying response plans and during the event itself, required the presence on site of a large number of project participants.

B.3.5 Fukushima

When a tsunami caused a breach of containment at several Japanese reactors, many of the project partners, as well as project equipment (RadEye PRDs from Health Canada) were diverted for a relief effort. Replacement PRDs were provided by CBSA, after they were added to the team as full project partners.

Table 3: Comparison of planned to actual schedule

Task	Milestone Event	Planned Completion Date	Actual Completion Date
1	Project Approval-in-principle	February 2008	February 2008
2	Project Implementation Workshop	March 2008	March 2008
3	Project Charter and signatures completed	May 2008	July 2008
4	Project implementation begins	June 2008	June 2008
5	Project Kick-off Meeting	June 2008	June 2008
6	PWGSC contract completed	November 2008	April 2009
7	Auditing "footprint" for modelling established	December 2008	February 2010
8	Modelling components integrated	May 2009	November 2010
9	Initial indoor test data produced, and Initial model verification occurs	August 2009	August 2010
10	RN Management Plan submitted	January 2010	January 2010
11	Initial outdoor test data produced, and Plume model verification occurs	March 2010	Summer 2010
12	Prototype Modelling Tool-Kit Developed	March 2010	July 2010
13	Series of "Dry Runs" performed	Summer 2010	May 2011
14	RN Management Plan accepted	August 2010	July 2011
15	CRTI progress report given	January 2011	December 2010
16	Initial Agent-Based Modelling code, – Phase I (detonation) completed	October 2010	Repurposed[1]
17	Final indoor test data produced, and Modelling Tool-kit refinement performed	March 2011	May 2012
18	Agent-Based Modelling – Phase II (break-up) completed	May 2011	Repurposed[1]
19	Final outdoor inert test results obtained	June 2011	July 2011
20	Live experiments – Phase I – results obtained	April 2011	June 2012
21	Modelling Tool-Kit refined and validated	September 2011	January 2012[2]
22	Agent-Based Modelling – Phase III – finalized	October 2011	
23	Live experiments – Phase II – results obtained	October 2011	October 2012
24	Modelling Tool-Kit refinements and validation Finalized	August 2012	March 2013[2]
25	Final refinement and validation of Agent-Based Modelling software performed	August 2012	Repurposed[1]
26	Transition "leave-behinds' to COE and CTTC	August 2012	December 2012
27	Project Close Out Report	December 2012	April 2013
28	Project Completed	December 2012	April 2013
29	Peer Review/CRTI Symposium Presentation/Success Story Publication	June 2013	June 2013

Note1: ABM was dropped from the project when international contract and IP issues made it impossible to hire the subject matter experts required. The funds were redistributed to the other modelling steam, and to the creation of the data-loggers
Note2: Model validation will be dependent on international partners, as per minutes from Nov 2011 PRC Meeting.

B.4 Cost performance summary

Table 4 shows the initially planned budgets (Charter v1) by fiscal year, compared to later Project Charters and the actual spending for the project.

Table 4: Planned vs. actual funds expended

Partner	Fiscal Year	Charter v1 June 2008	Charter v2 July 2010	Charter v4 Oct 2011	Actual Funds
Definition Funds	2008/09	$20,000	$20,000	$20,000	$20,000
DRDC Ottawa (RAD group + FFSE) (Lead Federal Dept.)	2008/09	$75,000	$66,822	$67,177	$67,177
	2009/10	$187,668	$182,413	$206,046	$206,046
	2010/11	$217,668	$316,229	$343,716	$343,716
	2011/12	$177,667	$314,157	$225,000	$225,000
	2012/13	$30,000	$294,696	$244,000	$125,460
Sub-total for DRDC Ottawa		**$708,003**	**$1,194,318**	**$1,105,939**	**$987,399**
ISR + Subcontractors	2008/09	$90,897	$90,744	$90,744	$90,744
	2009/10	$318,626	$308,253	$308,253	$308,253
	2010/11	$384,069	$173,577	$173,577	$173,577
	2011/12	$447,631	$307,430	$336,170	$336,170
	2012/13	$164,020	$129,740	$297,000	$297,000
Sub-total for ISR		**$1,405,243**	**$1,009,744**	**$1,205,744**	**$1,205,744**
DRDC Valcartier	2008/09	$20,000	$12,298	$15,029	$15,029
	2009/10	$94,483	$27,382	$28,454	$28,454
	2010/11	$154,491	$224,323	$43,599	$43,599
	2011/12	$176,080	$176,080	$110,000	$110,000
	2012/13	$65,027	$65,027	$65,027	$36,981
Sub-total for DRDC Valcartier		**$510,081**	**$505,110**	**$262,109**	**$234,063**
DRDC Suffield	2008/09	$60,000	$19,776	$19,776	$19,776
	2009/10	$77,621	$10,000	$10,000	$10,000
	2010/11	$52,850	$108,000	$19,371	$19,371
	2011/12	$79,082	$79,082	$150,000	$150,000
	2012/13	$37,000	$37,000	$66,411	$64,201
Sub-total for DRDC Suffield		**$306,553**	**$253,858**	**$265,558**	**$263,348**
Health Canada	2008/09	$30,000	$253,858	$29,286	$29,286
	2009/10	$180,000	$87,998	$87,998	$87,998
	2010/11	$275,000	$285,000	$285,000	$285,000
	2011/12	$80,000	$82,716	$60,000	$60,000
	2012/13	$0	$80,000	$190,000	$175,677
Sub-total for HC		**$565,000**	**$565,000**	**$652,284**	**$637,961**

Partner	Fiscal Year	Charter v1 Jun 2008	Charter v2 July 2010	Charter v4 Oct 2011	Actual Funds
NRCan	2008/09	$0	$0	$0	$0
	2009/10	$130,000	$130,000	$130,000	$130,000
	2010/11	$0	$0	$0	$0
	2011/12	$55,500	$55,500	$3,000	$3,000
	2012/13	$0	$0	$69,000	$69,000
Sub-total for NRCan		**$185,500**	**$185,500**	**$202,000**	**$202,000**
Environment Canada	2008/09	$2,000	$0	$0	$0
	2009/10	$2,000	$0	$0	$0
	2010/11	$15,000	$15,000	$0	$0
	2011/12	$15,000	$15,000	$1,200	$1,200
	2012/13	$2,000	$2,000	$28,800	$28,800
Sub-total for EC		**$36,000**	**$32,000**	**$30,000**	**$30,000**
CBSA	2008/09	--	--	--	--
	2009/10	--	--	--	--
	2010/11	--	--	--	--
	2011/12	--	--	$0	$0
	2012/13	--	--	$27,685	$10,492
Sub-total for CBSA		**--**	**--**	**$27,685**	**$10,492**
RMC	2008/09	$65,310	$27,810	$56,960	$56,960
	2009/10	$43,600	$51,950	$51,950	$51,950
	2010/11	$45,200	$45,200	$34,380	$34,380
	2011/12	$64,200	$64,200	$40,080	$40,080
	2012/13	$48,000	$48,000	$48,000	$15,963
Sub-total for RMC		**$266,310**	**$237,160**	**$231,370**	**$199,333**
Total by Fiscal Year	2008/09	$363,207	$266,736	$298,972	$298,972
	2009/10	$1,033,998	$797,997	$822,701	$822,701
	2010/11	$1,144,277	$1,167,329	$899,643	$899,643
	2011/12	$1,095,161	$1,094,165	$925,450	$925,450
	2012/13	$346,047	$656,463	$1,035,923	$823,574
GRAND TOTAL		**$3,982,690**	**$3,982,690**	**$3,982,690**	**$3,770,340**

The variances observed in the table can for the most part be related directly to the delays listed in the above section. The one notable exception to this is the shifting of a large portion of the modelling funds to ISR in year four. The determination had been made that, with the shifting of modelling to our international partners, funds could be efficaciously spent bolstering the data collection during the trials. To this end, ISR was contracted to produce the data-logging devices that preserved and transmitted the dose rate data from the RadEye PRDs in the detector array to the base station.

Table 5 shows a similar breakdown by year and partner for the in-kind expenditures.

Table 5: Planned vs. actual in-kind

Participant	Fiscal Year	Charter v1 In-Kind	Charter v2 In-Kind	Charter v4 In-Kind	Actual In-Kind
DRDC Ottawa (RAD group + FFSE) (Lead Federal Dept.)	2008/09	$420,134	$387,108	$387,108	$387,108
	2009/10	$321,619	$357,704	$357,704	$357,704
	2010/11	$328,152	$387,180	$282,000	$282,000
	2011/12	$341,292	$337,260	$358,100	$358,100[3]
	2012/13	$276,667	$216,667	$637,393	$949,073[4]
Sub-total for DRDC Ottawa		**$1,687,864**	**$1,685,919**	**$2,022,305**	**$2,333,985**
ISR + Subcontractors	2008/09	$46,000	$49,783	$49,783	$49,783
	2009/10	$181,000	$89,250	$89,250	$89,250
	2010/11	$142,000	$47,250	$52,319	$52,319
	2011/12	$142,000	$47,250	$47,250	$47,250
	2012/13	$48,000	$26,250	$26,250	$10,939
Sub-total for ISR		**$559,000**	**$259,783**	**$264,852**	**$249,541**
DRDC Valcartier	2008/09	$43,262	$34,931	$34,931	$34,931
	2009/10	$138,344	$106,675	$106,675	$106,675
	2010/11	$206,499	$236,499	$17,403	$17,403
	2011/12	$252,978	$262,978	$59,756	$59,756
	2012/13	$126,271	$126,271	$79,674	$62,713
Sub-total for DRDC Valcartier		**$767,354**	**$767,354**	**$298,439**	**$281,478**
DRDC Suffield	2008/09	$110,719	$10,822	$10,822	$10,822
	2009/10	$144,354	$244,251	$4,293	$4,293
	2010/11	$109,082	$109,082	$7,658	$7,658
	2011/12	$332,725	$332,725	$145,521	$145,521
	2012/13	$121,364	$121,364	$215,521	$210,113
Sub-total for DRDC Suffield		**$818,244**	**$818,244**	**$383,815**	**$378,407**
Health Canada	2008/09	$130,250	$130,250	$130,250	$130,250
	2009/10	$131,250	$131,250	$131,250	$131,250
	2010/11	$297,375	$297,375	$69,348	$69,348
	2011/12	$44,125	$44,125	$110,125	$110,125
	2012/13	$0	$0	$55,000	$298,476
Sub-total for HC		**$603,000**	**$603,000**	**$495,973**	**$739,449**

[3] $358,000 includes $308,100 from DRDC Ottawa, $40,000 from Sandia National Laboratories and $10,000 from US Department of Energy,

[4] $949,073 includes $416,905 from DRDC Ottawa, $170,000 from Sandia National Laboratories and the US Department of Energy, $106,368 from the UK Atomic Weapons Establishment, $102,000 from Atomic Energy of Canada Limited and $153,800 from the Canadian Joint Incident Response Unit

Participant	Fiscal Year	Charter v1 In-Kind	Charter v2 In-Kind	Charter v4 In-Kind	Actual In-Kind
NRCan	2008/09	$1,456	$1,456	$1,456	$1,456
	2009/10	$31,234	$31,234	$31,234	$31,234
	2010/11	$31,234	$31,234	$23,917	$23,917
	2011/12	$61,011	$61,011	$31,011	$31,011
	2012/13	$31,234	$31,234	$61,234	$98,000
Sub-total for NRCan		**$156,169**	**$156,169**	**$148,852**	**$185,618**
Environment Canada	2008/09	$15,000	$5,701	$5,701	$5,701
	2009/10	$15,000	$1,000	$1,000	$1,000
	2010/11	$15,000	$17,000	$700	$700
	2011/12	$15,000	$17,000	$2,000	$2,000
	2012/13	$15,000	$15,000	$30,000	$15,000
Sub-total for EC		**$75,000**	**$55,701**	**$30,000**	**$24,401**
CBSA	2008/09	--	--	--	--
	2009/10	--	--	--	--
	2010/11	--	--	$500	$500
	2011/12	--	--	$59,300	$59,300
	2012/13	--	--	$100,000	$100,000
Sub-total for CBSA		**--**	**--**	**$159,800**	**$159,800**
RMC	2008/09	$51,400	$32,000	$32,000	$32,000
	2009/10	$25,000	$34,400	$34,400	$34,400
	2010/11	$25,000	$35,000	$36,050	$36,050
	2011/12	$25,000	$25,000	$25,000	$25,000
	2012/13	$25,000	$25,000	$25,000	$25,500
Sub-total for RMC		**$151,400**	**$151,400**	**$152,450**	**$152,950**
Total by Fiscal Year	2008/09	$818,221	$651,315	$652,051	$652,051
	2009/10	$987,801	$996,500	$755,806	$755,806
	2010/11	$1,174,342	$1,160,620	$489,895	$489,895
	2011/12	$1,194,131	$1,127,349	$838,063	$838,063
	2012/13	$643,536	$561,786	$1,230,072	$1,769,815
GRAND TOTAL		**$4,818,031**	**$4,497,570**	**$3,965,887**	**$4,505,630**

Annex C Publications, presentations and patents

C.1 Scientific publications

1. Cao, X., Andrews, W.S. and Roy, G. (2010). "Modeling the concentration distributions of aerosol puffs using artificial neural networks." *Boundary-layer Meteorology,* **136(1)**: 83-103

2. Cao, X., Roy, G., Hurley, W.J. and Andrews, W.S. (2011) Dispersion Coefficients for Gaussian Puff Models." *Boundary-layer meteorology*, **139(3)**: 487-500

3. Cao, X., Roy, G., Brousseau, P., Erhardt, L. and Andrews, W.S. (2011) "A Cloud Rise Model for Dust and Soot from a High Explosive Detonation." *Propellants, Explosives, Pyrotechnics*, **36(4)**: 303-309.

4. Lebel, L.S., Brousseau, P., Erhardt, L., and Andrews, W.S. (2011) "Entrainment of Powders and Soils into Explosive Fireballs," *International Journal of Energetic Materials and Chemical Propulsion*, **10(4)**:351-364.

5. Lebel, L.S. (2012) "Aerosolization and Soil Entrainment in Explosive Fireballs" Ph.D. Thesis, Royal Military College, Kingston, ON. October 2012.

6. Lebel, L.S., Brousseau, P., Erhardt, L., and Andrews, W.S. (2013) "Measurements of the Temperature Inside an Explosive Fireball," *Journal of Applied Mechanics*, (in press).

7. Cao, X. (2013) "Analysis of Lidar measurement of plumes and puffs-Aug 2010 trials", (DRDC Valcartier CR 2013-xxx) Defence R&D Canada – Valcartier.

8. Cao, X. (2013) "Analysis of Puffs Dispersion- July 2010 trials", (DRDC Valcartier CR 2013-xxx) Defence R&D Canada – Valcartier.

9. Cao, X. (2013) Report on RDD Lidar Measurements at Suffield (DRDC Valcartier TR IOSL TR 2013-0001) Defence R&D Canada – Valcartier.

C.2 Significant presentations

1. Erhardt, L.S., "Canadian RDD Characterization Experiments." Cooperative US/CA Nuclear Forensics Workshop. Argonne National Laboratories, Chicago IL. July 2008.

2. Erhardt, L.S., "Canadian RDD Characterization Experiments – Modelling Implications". AUS/CAN/UK/US Explosive RDD Modelling Workshop. Sandia National Laboratories, Albuquerque NM. November 2008.

3. Erhardt, L.S., "RDD Hazard Modelling and Characterization Experiments". Science and Technology Intelligence Group (STIG) Meeting. Ottawa, ON. June 2009.

4. Erhardt, L.S., “RDD Hazard Modelling, Risk Assessment and Characterization Experiments”. CBR MOU International Task Force 53 (ITF-53) on Pre-event Radiological Standoff Detection. Ottawa, ON. June 2010.

5. Erhardt L.S., Quayle D., and Larsson, C.L. “Full-scale RDD Experiments and Models”. Science and Technology Intelligence Group Meeting. ASIO, Canberra, Australia, May 2011.

6. Lebel, L.S., Brousseau, P., Erhardt, E., and Andrews, W.S., “An Investigation of Aerosolization and Associated Phenomena Resulting from the Detonation of Explosives,” Proceedings of the 26th International Ballistics Symposium, Miami, FL, Sept. 12-16, 2011.

7. Zaidi, A. and Erhardt, L.S. “RDD Source Term Modeling”. AUS/CAN/UK/US RDD Workshop Sandia National Laboratories. Albuquerque, NM. December 2011.

8. Erhardt, L.S. and Quayle, D., “Large-Scale Outdoor RDD Trial Plans”. AUS/CAN/UK/US RDD Workshop. Sandia National Laboratories. Albuquerque, NM. December 2011.

9. Lebel, L.S., Brousseau, P., Erhardt, E., and Andrews, W.S., “Entrainment of Powders and Soils into Explosive Fireballs,” Proceedings of the 9th International Symposium of Special Topics in Chemical Propulsion, Quebec City, QC, July 9-13, 2012.

10. Harper, F., “Sandia source-term characterization overview”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

11. Parkes, D., “UK source-term characterisation overview (S)”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

12. Erhardt, L.S., “Review of configuration considerations and constraints”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

13. Brousseau, P. and Erhardt, L.S., “Experimental source configuration (S)”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

14. Parkes, D., “Experimental source hydrocode modelling”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

15. Harper, F., “Overview of Israeli field trials”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

16. Erhardt, L.S., Quayle, D. and Jones, T., “Conduct of the full-scale RDD field trials”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

17. Roy, G., Cao, X., Brousseau, P., Bernier, R. and Erhardt, L. “RDD Project: Scanning LIDAR Results”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

18. Korpach, E. and Berg, R. “RS250 NaI Monitors – Plume Passage”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

19. Erhardt, L.S. and Noel, S. “Thermo RadEye PRD Network for the FSRDD Field Trials”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

20. Okada, C., Van Etten, D., Sorom, R., “Air Particulate Sampling at RDD Trials”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

21. Keillor, M., Kernan, W. and Kirkham, R., “Far Field Air Sampling for DRDC Particle Release Trial”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

22. Erhardt, L.S., Quayle, D. and Watson, I., “Beta measurements at the FS RDD Field Trials”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

23. Fortin, R., Buckle, J., Sinclair, L., Seywerd, H., Van Brabant, R., Coyle, M., Harvey, B. and Al-Khoubbi, I., “NRCan's Airborne and Truckborne Data Acquisition”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

24. Erhardt, L.S. and Noel, S. “RadEye network – deposition results”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

25. Korpach, E. and Berg, R. “Deposition Results from the RS250 NaI Monitors and Ground Based Filters”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

26. Okada, C., Van Etten, D., Sorom, R., “In-situ gamma spectral measurements at RDD Trials”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

27. Sinclair, L and Fortin, R., ”Unfolding of airborne measurements”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

28. Nsengiyumva, D., “RDD Database - Canadian Version”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

29. Yu, K., Nasstrom, J. and Foster, K., “NARAC Modeling of the Canada Full-Scale RDD Field Trials”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

30. Purves, M., “Dispersion Modelling of FSRDD trials using HPAC and DIFFAL”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

31. Bensimon, D., Bourgouin, B., Ek, N. and Malo, A., “Overview of Dispersion Modelling as applied to RDD Experiment at CFB Suffield”. US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

32. Bensimon, D., Bourgouin, B., "Overview of meteorological conditions during the field trials". US/UK/Canada Conference on Full-Scale RDD Field Trials. Las Vegas, NV. February 2013.

33. Lebel, L.S., Brousseau, P., Erhardt, E., and Andrews, W.S., "Measurements of the Temperature Inside an Explosive Fireball," Proceedings of the 27th International Ballistics Symposium, Freiburg, Germany, Apr. 22-26, 2013.

34. Lebel, L.S., Brousseau, P., Erhardt, E., and Andrews, W.S., "Detonation Product Combustion in Explosive Fireballs," Proceedings of the 7th International Seminar on Fire and Explosion Hazards, Providence, RI, May 5-10, 2013.

C.3 Other significant documents

1. Fitzgerald, J. Erhardt, L.S., Green, A.R., White, D. and Quayle, D., Due Diligence EA for FS-RDD CRTI Radiation Trial - Explosive Dissemination of a Low Radioactive Source. DRDC Suffield Environmental Assessment Report. October 2011.

2. Erhardt, L.S. et al. (2012) Radiological Practice Approval Form CRTI-07-0103RD (RadPAF 2011-004) Defence R&D Canada – Suffield. 13 Feb 2012.

3. Billette, N., Erhardt, L.S., Green, A.R., White, D. and Quayle, D., Environmental Screening: Dispersion Modelling Field Trial. DRDC File #: 1267-1410-1212-01, CEA Registry #: 12-01-67220. April 2012.

4. Green, A.R. (2012) CRTI 07-103 RD Trials, ONTAP-0002-12 (DRDC Suffield Online Turbo Approval Process), 4 May 2012.

5. Erhardt, L.S., Quayle, D., Green, A.R., White, D., Noel, S., et al. (2012) Full-Scale Radiation Dispersion Device Experiment Plan Version 2.8. May 2012.

6. Erhardt, L.S., Quayle, D., Green, A.R. and White, D. (2012) After Action Report: Full-Scale RDD Spring Trial. August 2012.

List of symbols/abbreviations/acronyms/initialisms

˚C	Degrees Celsius
AAR	After Action Report
ABM	Agent Based Modelling
AECL	Atomic Energy of Canada Limited
AU	Acadia University
AWE	Atomic Weapons Establishment
Bq	Becquerel
CBRNE	Chemical, Biological, Radiological, Nuclear, Explosive
CBSA	Canadian Border Services Agency
CF	Canadian Forces
CFD	Computational Fluid Dynamics
CFX	Computational Fluid Dynamics
Ci	Curie
CJIRU	Canadian Joint Incident Response Unit
COE	Centre Of Excellence
CPS	Counts Per Second
CRTI	CBRNE Research and Technology Initiative
CSS	Centre for Security Science
CSSP	Canadian Safety and Security Program
CTTC	Counter Terrorism Technology Centre
CWMD	Combating Weapons of Mass Destruction
DGNS	Director General Nuclear Safety
DND	Department of National Defence
D N Safe	Director Nuclear Safety
DOE	Department of Energy
DRDC	Defence Research and Development Canada
EC CMC	Environment Canada Canadian Meteorological Centre
EPG	Experimental Proving Grounds
FE	Finite Element (analysis)
FFSE	Future Forces Synthetic Environments
FSRDD	Full-Scale RDD: Experiments and Models
FTP	Field Trial Plan
GBq	Giga Becquerel
GPS	Global Positioning System
GZ	Ground Zero
h	hours

HC RPB	Health Canada Radiation Protection Branch
HPAC	Hazard Prediction and Assessment Capability
HPGe	High Purity Germanium
IP	Intellectual Property
IR	Infra-Red
ISR	International Safety Research
km	kilometer
LIDAR	Light Detection And Ranging
m	meter
MDT	Mountain Daylight Time
m/s	Meters per second
N/A	Not Applicable
NaI	Sodium Iodide
NECSI	New England Complex Studies Institute
NEW	Nuclear Energy Worker
NNSA	National Nuclear Security Administration
NRCan	Natural Resources Canada
PNNL	Pacific Northwest National Laboratories
PRAT	Probabilistic Risk Assessment Tool
PRC	Project Review Committee
PRD	Personal Radiation Detectors
PPE	Personal Protective Equipment
PWGSC	Public Works and Government Services Canada
QA/QC	Quality Assurance/Quality Control
RAD	Radiological Analysis and Defence
RadPAF	Radiological Practices Approval Form
RadSO	Radiation Safety Officer
RCMP	Royal Canadian Mounted Police
RDD	Radiological Dispersion Device
RMC	Royal Military College
RSL	Remote Sensing Laboratories
SNL	Sandia National Laboratories
SPH	Smoothed-Particle Hydrodynamics
TBD	To Be Determined
TDG	Transport (of) Dangerous Goods
TSWG	Technical Support Working Group
UK	United Kingdom
US	United States (of America)
US DTRA	US Defense Threat Reduction Agency
UXO	Unexploded Ordinance

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – Ottawa 3701 Carling Avenue Ottawa, Ontario K1A 0Z4	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED (NON-CONTROLLED GOODS) DMC A REVIEW: GCEC JUNE 2010

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Completion report for CRTI 07-0103RD: "Full-Scale RDD Experiments and Models"

4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

Erhardt, L.S.; Quayle, D.; Noel, S.

5. DATE OF PUBLICATION (Month and year of publication of document.) October 2013	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.) 72	6b. NO. OF REFS (Total cited in document.) 13

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – Ottawa
3701 Carling Avenue
Ottawa, Ontario K1A 0Z4

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) CRTI 07-0103RD	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC Ottawa TR 2013-056	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

In order to gather more and more accurate information on the behaviour of Radiological Dispersion Devices (RDDs), a set of experiments was performed. These experiments built on the existing body of knowledge and included many of the world's leading authorities in RDD physics, modelling and atmospheric dispersion. Beginning with indoor tests to characterize the explosive used to perform the dispersion of our radioisotope, the experiments culminated in a series of three outdoor releases of a short-lived tracer isotope, 140La.

The dispersion and deposition from these outdoor explosive releases were monitored and recorded using a wide variety of instruments. Radiation was monitored using fixed point large volume gamma detectors, a large number of small volume gamma detectors (260), truck and helicopter mounted spectrometry equipment, hand-held survey instruments, and air-samplers. Weather conditions were monitored from three mobile meteorological stations, as well as through the launching of weather balloons. There were also LIDAR, high speed video, and wide-field video monitoring of the explosions and subsequent plumes.

The unique data sets gathered during these releases fed existing RDD modelling efforts and will be shared with our allies to inform future generations of models and risk assessments.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

RDD; dispersal; radioactive; risk assessment; CBRN; RN; dirty bomb; detection; atmospheric dispersion

Defence R&D Canada

Canada's leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE DÉFENSE

www.drdc-rddc.gc.ca