Innovations Deserving Exploratory Analysis Programs

Transit IDEA Program

Detection of Radioactivity in Transit Stations

Final Report for
Transit IDEA Project 42

Prepared by:
Dr. Eric P. Rubenstein
Advanced Fuel Research, Inc.
East Hartford, CT

October 2006

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Innovations Deserving Exploratory Analysis (IDEA) Programs

Managed by the Transportation Research Board

This Transit IDEA project was funded by the Transit IDEA Program, which fosters development and testing of innovative concepts and methods for advancing transit practice. The Transit IDEA Program is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP), a cooperative effort of the FTA, the Transportation Research Board (TRB) and the Transit Development Corporation, a nonprofit educational and research organization of the American Public Transportation Association (APTA).

The Transit IDEA Program is one of four IDEA programs managed by TRB. The other IDEA programs are listed below.

- NCHRP Highway IDEA Program, which focuses on advances in the design, construction, safety, and maintenance of highway systems, is part of the National Cooperative Highway Research Program.
- High-Speed Rail IDEA Program, which focuses on innovative methods and technology in support of the Federal Railroad Administration's (FRA) next-generation high-speed rail technology development program.
- Safety IDEA Program, which focuses on innovative approaches for improving railroad safety and inter-city bus and truck safety. The Safety IDEA program is funded by the Federal Motor Carrier Safety Administration and the FRA.

Management of the four IDEA programs is coordinated to promote the development and testing of innovative concepts, methods, and technologies.

For information on the IDEA programs, look on the Internet at www.trb.org/idea or contact the IDEA programs office by telephone at (202) 334-3310 or by fax at (202) 334-3471.

IDEA Programs

Transportation Research Board

500 Fifth Street, NW

Washington, DC 20001

Detection of Radioactivity in Transit Stations

Final Report

Transit IDEA Project 42

Prepared for

Transit IDEA Program

Transportation Research Board

National Research Council

Prepared by

Dr. Eric P Rubenstein

Advanced Fuel Research, Inc.

East Hartford, CT

October 2006

ACKNOWLEDGEMENTS

The Principal Investigator and AFR, Inc. would like to acknowledge the support of the Transportation Research Board's Transit IDEA Program, under contract TRANSIT-42.

The project has benefited from the valuable input of the AFR team, which includes: Dr. Marek A. Wójtowicz, Dr. Michael A. Serio, Mr. Keith Reynolds, Dr. Peter Solomon, and Mr. Kenneth Wexler. Their contributions have helped to shape this technology and prepare it for the marketplace. The support of Karin Dutton, Helen Sokolowski, and Susan White is gratefully acknowledged.

The generous contribution of time and energy by the following individuals, their involved colleagues, and their organizations are also appreciated:

- Washington Metropolitan Area Transit Authority (WMATA): LT George Burns, Metro Transit Police Department; Mr. Fred Goodine, Assistant General Manager, Safety and Security, and others
- Connecticut Department of Transportation (CT-DOT): Director of Research Department, Mr. Jim Sime, P.E.
- Gil'ad N. Cohen, MS, DABMP, Radiotherapy Physicist, Memorial Sloan-Kettering Cancer Center
- Prof. Charles D. Bailyn, Yale University Astronomy Department
- Dr. Robert Singleterry, NASA Administrator's Fellow with Radiation Group of Computational Structures and Materials Branch, NASA Langley Research Center
- LiveWave Inc.: Mr. Jamie Edgars, Senior Vice President, and others
- TRB, Transit IDEA Program: Mr. Harvey Berlin, Senior Program Officer
- The individuals at the meeting mentioned on page 5

Table of Contents:

LIST OF FIGURES:

LIST OF TABLES:

Detection of Radioactivity in Transit Stations

Transit IDEA Project 42

1. EXECUTIVE SUMMARY

The purpose of this Transit IDEA project was to develop a prototype system to detect dangerous levels of radioactivity in rail transit stations. Transit stations could be potential targets for terrorist attacks because they carry large numbers of people daily. To protect against that threat, pervasive radiation detection is important.

This project addresses the efforts at Advanced Fuel Research to address special detection problems due to limited line-of-sight regions arising from radiation blocking obstructions, e.g. concrete, steel, and earthen walls and supports in collaboration with representatives from the Washington Metropolitan Area Transit Authority (WMATA). An essential part of this technology development and demonstration project is the feedback from the Expert Review Panel, includes WMATA, federal and state agencies, industry, and academia.

The Radiation Event Detection System: Tracking And Recognition™ (RedStar™) technology is based upon the innovation of using existing digital cameras with Charge Coupled Device (CCD) light detectors as radiation measuring sensors (Patent Pending). Modern security cameras often use these detectors, and are already connected to an operations center. The addition of our software running on commercial-off-the-shelf (COTS) computers allows the security cameras to be transformed into radiation detectors, while still able to perform their primary mission of optical image capture. Radiation detection equipment is typically expensive if not integrated with already existing and deployed security infrastructure including the security camera. Figure 1 shows a schematic of the RedStar system. These sensors have sufficient sensitivity to detect dangerous levels of radioactivity, as measured in our laboratory experiments, and discussed below.

During the work, we demonstrated that the digital cameras were able to detect radiation. The evidence for this capability is very compelling, and can even be seen by eye in images that do not have a bright, complex background. Figure 7 shows an example of such data taken at our field test, performed at Memorial Sloan-Kettering Cancer Center (MSKCC). The red arrows point to specific instances where gamma-rays from decaying Cesium-137 (Cs-137) struck, and were detected by the camera's CCD sensor. The MSKCC field tests confirmed our earlier laboratory results that digital cameras could be used as radiation detection sensors. We used very small radiological sources in the lab due to safety considerations. However, those sources were too small to be able to mirror a realistic threat scenario, such as those evaluated by the Federation of American Scientists in their testimony before congress [4]. In order to put our laboratory results onto a more useful scale, we calculated the response expected from a range of radiological sources from the tiny sources used in medical procedures up to the 10,000 Curie (Ci) source the FAS considered.

Figure 2 shows the expected range of detectability for a range of source strength. Large sources are detectable at hundreds or even thousands of feet, while progressively smaller sources must approach to within correspondingly smaller distances from a camera that is being monitored with our software. Having worked with WMATA, we are familiar with their deployment of cameras. Stations such as the one shown in Figure 3 are designed to have at least two cameras able to see each square-foot of station property. That means that if deployed throughout a WMATA station, there would always be *at least* two cameras with unobstructed views to a potential radiological source, with a correspondingly higher probability of detection.

The technical success of the work in this project and the extensive collaboration with WMATA has prepared us for proposed follow-on work to install and evaluate a RedStar system into a WMATA Metro station. In preliminary planning with WMATA Metro Transit Police, we have identified the Anacostia station as the site for the expected prototype test. We will coordinate the installation with ESS, an engineering and integration company that is performing an installation of video analytics software at that station. Prior to the actual installation, we will coordinate the concept of operations (CONOPS) with WMATA. Our meetings have pointed out the extreme importance that any software-generated alerts be compliant with their expectations, and that the desired level of sensitivity be balanced by their goal to minimize false positive alerts.

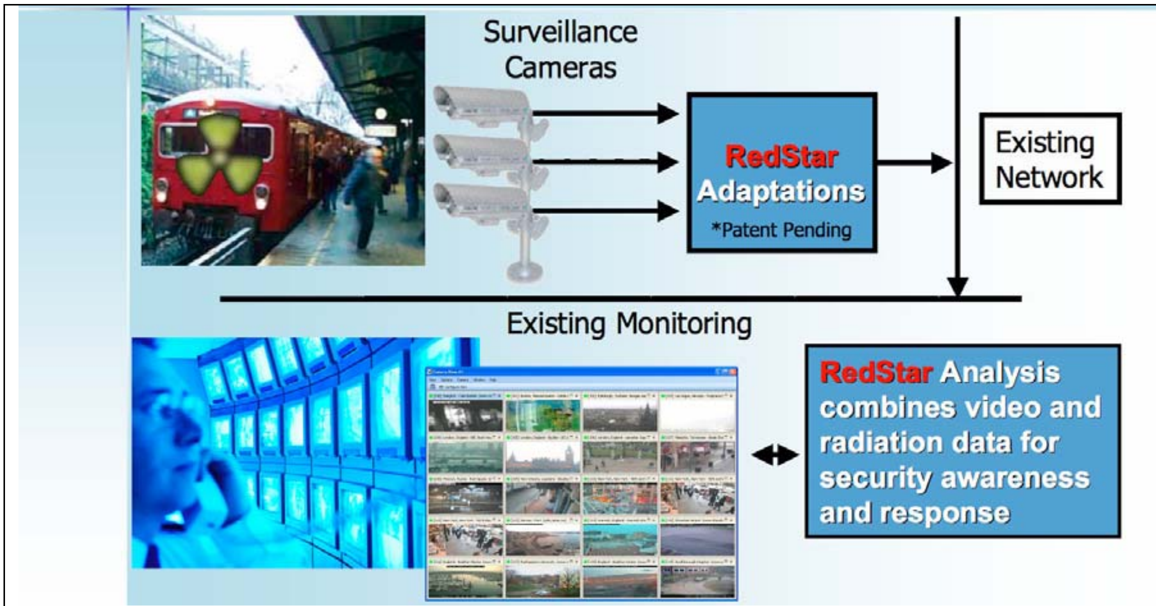

Figure 1: Schematic of RedStar system in which existing security cameras transmit their video-feed through existing network infrastructure to either the transit station's security office or the Network Operations Center (NOC). At the desired location, the video images are analyzed by the RedStar analysis routines. Should a very reliable detection occur, the nature of the problem and the recommended action would be relayed to the security officer standing watch. In proposed Phase 2 follow-on work, AFR plans to work closely with Washington Metro Transit Police to capture their concept of operations (CONOPS) and embed their desired outcomes and alerts into the RedStar system.

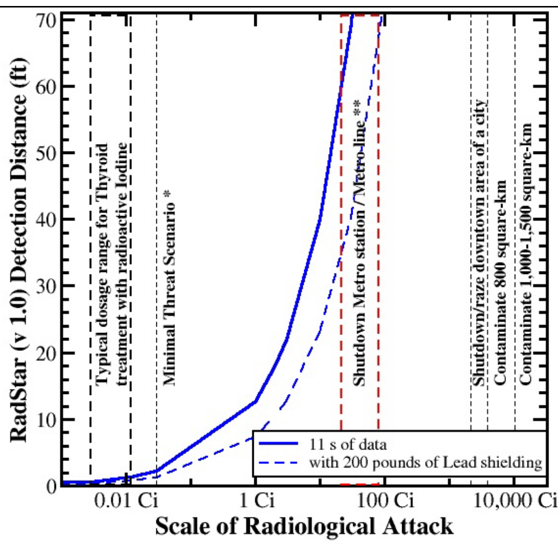

Figure 2: Laboratory sensitivity curve for RedStar radiation detection system. 15 μCi of Cs-137 was detected using a COTS digital camera and our software. The 6-σ detections formally indicate a 10^{-6} probability of missing a source of the indicated size or larger, at the distance shown. The dotted line displays projected sensitivity for a hypothetical case of 200 pounds of lead shielding.

Figure 3: The RedStar pervasive grid enables us to monitor the radiation environment anywhere a digital camera is placed. The cameras near the Metro entrance, turnstiles, and stairs could detect a source entering the system, while cameras on successive platforms follow radiological sources in transit from station to station.

2. IDEA PRODUCT AND POTENTIAL IMPACT ON TRANSIT PRACTICE

The fully developed product will be a software/hardware product that will allow dirty bombs to be detected using modern digital security cameras as the radiation detector. This product will augment other radiation sensors and enable high-level coordination by transit and law-enforcement authorities. Network-enabled software, using common communication interfaces, will facilitate the dissemination of alerts to key stakeholders in transit and government activities.

The ubiquitous distribution of security cameras in many rail rapid transit systems ensures that dangerous amounts of radioactive material will have to pass within detection-range. For example, in the Washington Metro system, the stations are designed and equipped so that any given spot in the station is observable from at least two cameras. Therefore, at least two cameras may be able to detect a radiological source no matter where it is carried within a station. Similarly, multiple cameras will have to be approached and passed as a radiological source is carried into a station. Unlike portal scanners that require individuals to file past one at a time, this IDEA product will not slow down passengers entering the system. Portal scanners, such as magnetometers that are used at airports, take a long time because people must go through one at a time.

Successful deployment of this invention will enable transit facilities to inexpensively enhance their security infrastructure. A key factor in its implementation is that the sensors are cameras already existing in many rail rapid transit systems. The relatively small buy-in cost suggests that RedStar technology may be broadly and quickly applied in the transit market.

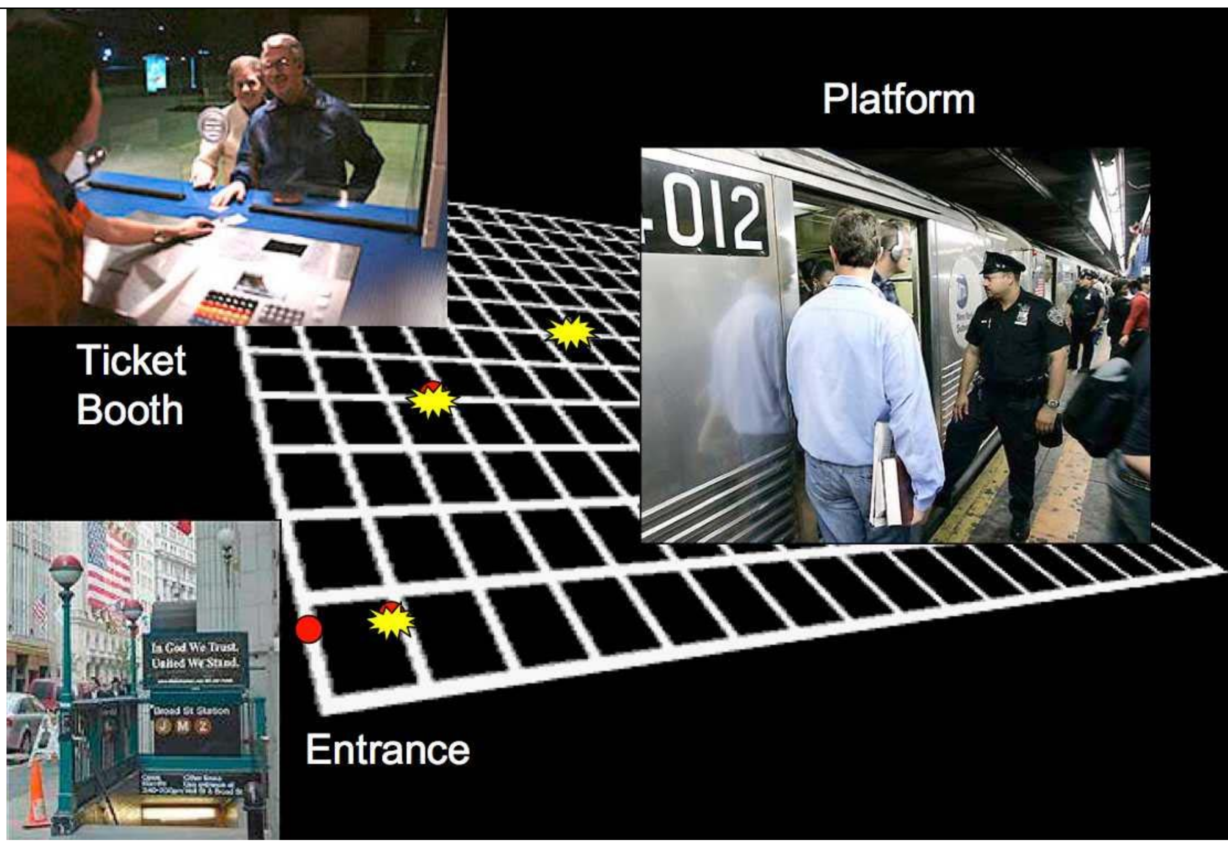

Figure 4: The concept of deployment for RedStar technology within the transit market calls for a pervasive grid of security cameras to provision computer servers in network operating centers with the collected imagery. This vast data stream will be analyzed for the tell-tale signal of radiation. The pervasive grid will not impede traffic, and is therefore a good match to busy transit sites.

3. CONCEPT AND INNOVATION

The objective of this Transit IDEA project was to quickly produce a working prototype system based upon the innovation identified above. Briefly, the prototype implements a proprietary method of analysis (Patent Pending) to use digital imagery data to search for the telltale artifacts caused by radioactivity that hits and interacts with the Charge Coupled Device (CCD) detector within the digital camera. Most transit security cameras are connected to a Network Operations Center (NOC). Therefore, the envisioned system, described in the next section, allows for extremely efficient use of existing resources. The system makes use of existing detectors, data acquisition systems, communication networks, and centralized security staffing. The RedStar algorithms run on standard PC's, which minimizes the cost of "buy-in."

A U.S. Patent application has been filed for this method and process.

4. INVESTIGATION

4.1 TASK 1 – THE EXPERT REVIEW PANEL

The Principal Investigator (PI), Dr. Eric P Rubenstein, of Advanced Fuel Research, Inc. (AFR), has worked with the Senior Program Officer (SPO), Mr. Harvey Berlin, of the Transportation Research Board (TRB) to establish an Expert Review Panel (ERP). The goal of the ERP is to provide technical and transit-related feedback to benefit the development of the technology, and assist in the assessment of project milestone achievements. If the technology developed is deemed valuable to the transit industry, the ERP's advice will be valuable in matching the technology's capabilities with the industry's needs. Since the beginning of the contract period, a number of individuals have joined the ERP; these people are identified below. The Washington Metropolitan Area Transit Authority (WMATA) is a key transit partner to AFR in the performance of this Transit IDEA project. LiveWave provided technical help in integrating our technology with WMATA's security infrastructure. In particular, they advised us on how to collect images from the IP cameras.

4.1.1 Preliminary Meetings:

A pre-award meeting was held with Mr. Fred Goodine of WMATA, Mr. Harvey Berlin of TRB, and Dr. Eric Rubenstein, the PI. At that meeting, it was agreed that WMATA would provide a letter to the PI confirming WMATA's participation in this project. The letter indicated that a field-test of the Radiation Event Detection System: Tracking And Recognition (RedStar™) radiation detection package could be performed at one of the Washington Metrorail facilities. LT George Burns, of WMATA's Metro Transit Police, was the primary point of contact (POC) for WMATA.

A meeting between WMATA security personnel, the PI, Dr. Michael Serio, President of AFR and Mr. Harvey Berlin of TRB was held on 6 April 2005. At that meeting, the PI presented to WMATA representatives details concerning a proposed Concept of Operations (CONOPS) and level of sensitivity to radiation achieved in our laboratory tests (in Task 3, below); LT Burns and his colleagues agreed to help coordinate future collaborative efforts, including a field test. They identified three particular Metrorail stations as possible prototype testing locations: Union Station due to its strategic position as the gateway between the Metrorail system and intercity passenger railroad services; Judiciary Square, due to its relatively high background-level; and Mt. Vernon, due to its all digital infrastructure and assortment of new cameras. Data were then collected from Union Station and Judiciary Square Metro stations.

Part of the meeting involved general discussions about the concepts of operations that would allow for the integration of RedStar with WMATA's Metro Police procedures. Although it was deemed premature to develop detailed plans for such CONOPS, a few trends were apparent. (1) An essential element of RedStar deployment will be the need to involve tight coordination of multiple jurisdictions, including: WMATA's Metro Police, Washington Police, DHS, the FBI, DOD, DOE, and other agencies. Indeed, different locations

might have different protocols (e.g. Pentagon vs. an outer station), depending upon the local security requirements. (2) Training for Network Operations Center (NOC) personnel must not be long, difficult, or highly specialized. One concept for deployment discussed was that if an alert were to occur, a message would be displayed that provide details of the detected event (e.g. source activity level, isotope identification if possible, etc.), and what response plan should be implemented (e.g. send an officer to investigate; remove passengers from a station; monitor and track more intensively, etc.). In order to derive an appropriate menu of response plans, it will be necessary to first determine the sensitivity of the RedStar system in transit stations, and then for WMATA to work with the relevant federal agencies to formulate a general plan. Ultimately, different protocols may be instituted on a site-by-site basis, according to the detected level of alert and other relevant factors.

4.1.2 Initial Expert Review Panel Meeting:

On 18 April 2005, a formal meeting of the ERP was held. Attending were: Mr. Brian O'Malley (TSA), Mr. Harvey Berlin (TRB), Mr. Neil Hawks (TRB), Mr. Stephan Parker (TRB), Dr. Mattson (Bechtel/DOE), Mr. Mark Miller (WMATA), Lt. Leslie Campbell, Metro Transit Police Department (MTPD), LT Ron Bodmer (MTPD/SARP), Mr. Michael Taborn (FTA), Ms. Jeanette O'Hara (FTA), Mr. Jason Mangen (MTPD), Mr. Matt Greenwald (WMATA), LT George Burns (MTPD), and Dr. Eric Rubenstein (AFR Inc.). At this meeting, the agenda included the following topics: a technical description of the RedStar technology (in Task 2), the laboratory sensitivity achieved to date (discussed in Task 3), the concepts of operations, availability of alternative technologies, and the collateral benefits for WMATA security infrastructure if RedStar were broadly deployed.

We also discussed some of the plans for improvements to the technology. Probably the most important requirement is to be able to determine the type of radioactive material present. This requirement can likely be met. From a technical point of view, the signal generated in the CCD is proportional to the energy of the inbound γ-ray. With our proprietary software, the energy spectrum can be determined from the collected data. CCD's have been used to obtain energy measurements accurate to $2\% \leq \Delta E/E \leq 10\%$ [1], per γ-ray. That holds the opportunity for not merely detecting radioactivity, but for identifying the nature of its source as well, namely, the isotope generating the γ-rays. This future capability is considered by the ERP to be essential, and is a high-priority for implementation.

4.1.3 Other Meetings with Expert Review Panel Members:

Numerous conversations, e-mails and meetings with other advisors took place during Stage I of this project. Three of these advisors have been especially helpful, and are briefly mentioned here. They are: Prof. Charles Bailyn, Chairman of the Yale University Astronomy Department, an expert on detection of radiation using semi-conductor devices; Dr. Robert Singleterry, a nuclear scientist at NASA's Langley Research Center; and Mr. James Sime, P.E., the Head of the Connecticut Department of Transportation's Research Department.

Prof. Bailyn has spent much of the past 20 years studying astrophysical objects that emit radiation. He is an expert at analyzing CCD data, X-ray and γ-ray data, and at solving operational, technical and programming problems related to high-rate data acquisition and analysis. He serves as a technical advisor in these areas.

Dr. Singleterry is a NASA Administrator's Fellow, and an expert in the field of radiation shielding. In addition to providing general radiation-related expertise, he has also run computer simulations to assess the likely sensitivity of the RedStar system in a variety of circumstances. These calculations were used to assess the suitability of using RedStar in transit and other applications, as a function of the distance, speed and degree of shielding associated with a radioactive source.

Mr. James Sime has served as a connection between AFR and the Greater Hartford Transit District, and as a transit and transportation resource. He attended a laboratory demonstration of the initial prototype and provided guidance regarding its incorporation into a transit security system.

4.2 TASK 2 – BUILD PROTOTYPE AND INTEGRATE WITH SOFTWARE

4.2.1 The Prototype and the Envisioned System:

RedStar detection software runs on a standard computer, making use of a modern digital camera. Our proprietary (Patent Pending) software detects the interaction between high-energy particles from radioactive material and the camera's semi-conductor detector (e.g. CCD). There are many ways in which this technology may be deployed, but the most obvious transit application involves the centralized processing of transit security video images at either a station-level or system-wide NOC. Data collected from a specific camera in a station would be routed to the NOC where it would be made available to the RedStar components. Each image can then be analyzed. The software searches each image for the presence of static-like spots that result from high-energy radiation. The data processing happens very quickly, allowing detection to be made in real time.

Since many image frames are analyzed, the probability of generating a false-positive alert can be tremendously reduced. In operation, an alert would only be considered a candidate if the level of radioactivity remains elevated for some extended period of time, perhaps a few seconds.

In our Concept of Operations (CONOPS), the data from many cameras are all analyzed, and the results are pooled together for higher-level analysis. For example, if a radioactive source were carried into a transit station, it would pass in close proximity to an entryway camera, followed by one or more cameras in the fare area, before moving to the train platform. Once down there, the relative amount of radiation received by cameras would provide a clue as to the approximate location of the source. Additional, more advanced techniques to further refine the location determination are under study.

The goal of current development efforts is to increase the automation of the software system. This is important because labor-intensive human intervention is required to move the data from acquisition to format conversion and analysis stages using the initial prototype. In particular, it was necessary to transport data from one computer platform to another, which made it difficult to reduce the system to a frame-by-frame pipeline. Batch processing is deemed undesirable since it usually implies a longer amount of time will elapse between when data is taken, and the first opportunity at which an alert could be generated. Although relatively slow, the early prototype is perfectly acceptable for developmental work, and it was used for the initial calibration experiments, discussed in Task 3. The current work to increase the efficiency of the data acquisition workflow is compared to the initial work in Table 1. The field test at Memorial Sloan-Kettering Cancer Center used the second prototype.

Breaking the dependency on batch processing is the key step in reducing acquisition chain latency. One way to accomplish this step is by directly accessing individual image frames, for example, by using internet protocols to download the data directly to the working location. LiveWave Inc., a company that provides a number of services related to video streaming, is providing consultation services to AFR to facilitate data acquisition and alert dissemination. They are already working with WMATA, and are therefore able to be extremely helpful in these regards.

Table 1: Comparison of data acquisition chain in early prototype vice current development prototype

Initial Prototype:	**Second Prototype:**
Acquisition steps	Acquisition steps
1 - Take video	1 - Request and receive an image from LiveWave FirstAlert™ server
2 - Extract individual frames	2 - Convert data format
3 - Move frames from windows system to Unix development computer	3 - Begin analysis
4 - Convert data format	
5 - Begin analysis	
↓ ↓	↓ ↓
Human-in-loop	Automated script
Batch processing	Individual processing

In particular, LiveWave has provided detailed assistance to allow us to acquire individual image frames from their video server, called FirstAlert®. The current work effort involves redesigning our procedure to use the Application Protocol Interface (API) provided by LiveWave.

4.2.2 Developmental Interface:

A good design for the interface between RedStar and transit security and police is essential. Although early development benefits from technical output (in Figure 5), such data is not helpful in an operational security environment. Discussions at the ERP meeting provided useful input, which will be combined with subsequent advice and incorporated into a future release.

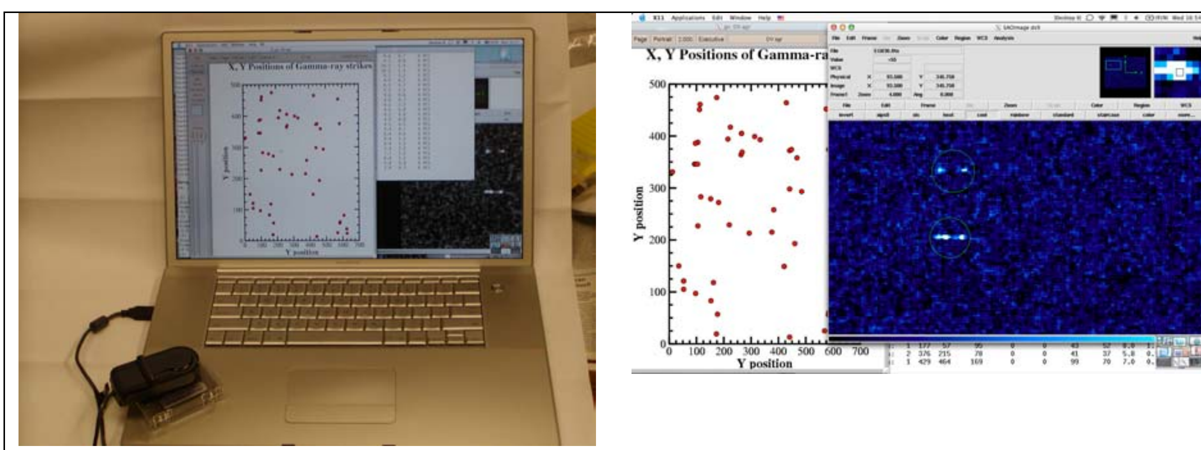

Figure 5: Left photograph shows early RedStar output running on a laptop using a webcam. Close-up of the results, on right, show technical data that are not expected to be part of the deployed interface.

One key aspect of the user interface is the need for the approved action plan to be part of the alert process. That is, a persistent alert should: [1] be identified by location; [2] be timely; [3] specify the previously decided-upon response. Examples of responses include: catalog the alert data for informational purposes if low level radioactivity is detected; engage police response if higher levels of radioactivity are found; or stop trains from entering and leaving a station until further information is collected. Later capabilities to specifically identify the isotope will also be incorporated into the action plan and may or may not be presented on the initial alert report. The participants in the ERP expressed a desire that should an alert be generated, it must supply to the operator the correct response for his/her action.

4.3 TASK 3 – MODELING OF DETECTION EFFICACY OR TESTING WITH SPECIFIC CALIBRATED ISOTOPES

Laboratory tests were conducted to evaluate the sensitivity of the hardware detection technologies. We performed tests using three different radioactive sources [2]: (1) 1 μCi Cobalt-60, (2) 5 μCi Cesium-137, and (3) 10 μCi Cesium-137. The Cobalt-60 source emits powerful 1.17 MeV and 1.33 MeV gamma-rays (γ-rays). These energetic rays are very penetrating, with only half of such γ-rays being absorbed after traversing 11 mm of lead. Our system is sufficiently sensitive to detect the 1 μCi source at a distance of 1.5 cm. Cesium-137 emits 0.66 MeV γ-rays, which are nearly as penetrating as those from Co-60. Half of Cesium-137's γ-rays penetrate 5.5 mm of lead. The Cesium sources have also been detected in the laboratory. Energetic γ-rays require significant amounts of lead shielding; therefore, it is very unlikely that pedestrians could carry enough shielding to prevent the detection of a significant source.

We would like to know how our laboratory detections translate into realistic threat environments. The Federation of American Scientists performed a number of calculations to assess the likely impact of various dirty bomb scenarios. The results of their detailed investigations can be found on the FAS website [3,4]. One of these case studies considered the case of a 10,000 Curie source of Cobalt-60. Such a source is 10^9 times more active than the 10 μCi Cesium source and 10^{10} times more active than the 1 μCi Cobalt source. For our preliminary calculation, we did not assume any change of source geometry or self-shielding. Air-attenuation becomes important for distances greater than roughly 100 meters, at which point air becomes an important component of the shielding calculations. For smaller distances, the main effect is the fall-off of intensity that is proportional to the square of the distance between source and detector. Dr. John Mattson, a Senior Scientist with Bechtel, who works at DOE's Argonne National Lab, pointed out at the 18 April 2005 meeting that Compton scattering of γ-rays will make sufficiently large sources visible from larger distances than might otherwise be the case. Our laboratory detections took place with a 1.5 cm distance. With the above assumptions, for a source 10^{10} times more active than our Cobalt-60 source, a comparable detection could be made when it is $\sqrt{10^{10}}$ x 1.5 cm = 1500 meters away. This is significantly larger than the distance over which air-attenuation becomes important. Alternatively, a source that is 100 Ci would be detectable at a distance of 15 meters, with the same, very highly significant statistics of our laboratory work. Dr. Mattson is concerned that the sensitivity may not be high enough to detect small sources. Live field tests have now demonstrated the expected "real world" sensitivity, and are discussed below. We will work closely with WMATA and DOE to assess whether the achieved values are of interest for further development.

4.4 TASK 4 – TEST PROTOTYPE

Initial meetings with WMATA and the ERP meeting on 18 April 2005 explored the options available for the field test. WMATA representatives where concerned that there might be adverse public sentiment if radiological material were to be introduced into the Metro facilities, even during non-operating hours. The ERP concluded that it might be best to split the field test into two distinct efforts. The first test would involve collecting data at a Metro station for analysis and measurement of the background radiation level. The second test would take place at a different (non-transit) site that already has a significant radioactive source. That

source will serve as a proxy for a dirty bomb, and would therefore need to be in a highly controlled environment.

The PI met with WMATA's POC, LT Burns, Dr. Tony Policastro of Argonne National Lab, Dr. William Dunn of the University of Chicago, and Mr. Harvey Berlin of TRB on 18 May 2005. The first portion of the prototype test was performed at that time. Data were collected from two Metro stations, Judiciary Square and Union Station. The 40 minutes of data were of good quality and did not produce a false alarm. See Figure 6 for examples from the Union Station Metro facility. Figure 6 shows sample images from Camera 1 near the entrance and Camera 7 above the platform.

Additional testing was performed at Memorial Sloan-Kettering Cancer Center (MSKCC) using their calibrated radiation sources (in Figure 7). A letter from MSKCC is shown on the next page. The sources that we evaluated are listed in Table 2.

Table 2: Radioactive Sources Studied at Memorial Sloan-Kettering Cancer Center

Isotope	**Source Type**	**Quantity**	**Distances (in)**	**Detected?**
Iodine-125 (I-125)	γ	3.5 mCi	1	No
Iodine-125 (I-125)	γ	10.6 mCi	1	No
Cesium-137 (Cs-137)	γ	2.65 mre	2,4,12,24	Yes for all
Ruthenium-106 (with Rhodium + balance of decay chain)	Predominately β and some γ	55 uCi	1	Yes
Iridium-192 (Ir-192)	γ	5.85 Ci	48, 96, 120	Yes for all

Eric Rubenstein, PhD
Senior Physicist
Advanced Fuel Research, Inc.
87 Church Street, East Hartford, CT 06108

Monday, August 14, 2006

Dear Dr. Rubenstein,

It was a pleasure to make Memorial Sloan-Kettering facilities available for testing of your video-centric radiation detection system. This letter is to confirm the tests you conducted on December 23, 2005 at our cancer treatment facility in New York City.

The system tested comprises of a digital camera, and a computer running proprietary software to acquire the image data. The digital camera was exposed to the following radioisotopes:

Isotope	Symbol	Quantity	Mean energy /keV
Iodine-125	^{125}I	3.5 & 10.6 mCi	28 (γ)
Cesium-137	^{137}Cs	2.65 mRaEq	662 (γ)
Ruthenium-106	^{106}Ru	55 μCi	3540 (β-)*
Iridium-192	^{192}Ir	5.85 Ci	380 (γ)

*Ru-106 and its daughter Rh-106 also decay via multiple γ peaks of up to 1.6 MeV.

The experiments were carried out over a range of distances up to 24 inches for the low activity sources, the greatest distance available in the lead-lined storage-bay, and 120 inches for the Ir-192 in a treatment room. During the tests, I observed the successful detection of each of these isotopes, though I have not made an extensive review of the data resulting from the tests. Ru-106 was also detected; here the signal was likely a combination of the photons emitted as well as secondary bremsstrahlung X-rays were produced by β- particles hitting the camera body. These initial data demonstrate that, in the laboratory setting, detection of radioactive material is possible.

Memorial Sloan Kettering maintains a calibration of radiological sources as recommended by the American Association of Physicists in Medicine. All source calibrations (except ^{106}Ru) are traceable to the National Institute of Standards.

I am looking forward to seeing the progression of this technology. If commercially available, it could offer interesting applications for internal and perimeter security for facilities such as hospitals, research centers and food irradiation plants, where radioactive materials are stored. I wish you well with your commercialization efforts. Should you wish to carry out additional calibration experiments, we welcome your request.

Yours sincerely,

Gil'ad N. Cohen, MS, DABMP
Radiotherapy Physicist
Department of Medical Physics
Memorial Sloan Kettering Cancer Center
1275 York Avenue
New York, New York 10021

Figure 6: Above two images from camera 1 at the Union Station Metro station in Washington D.C.; below are two images from camera 7 at the same facility. These well-illuminated images are typical of transit security video footage near the entrance/exit of transit stations. The algorithms used to identify radiation did not issue false alarms during the analysis of the video collected during this field test. The two images below are typical of the platform during periods of low-traffic (below-left) and high-traffic (below-right). In the lower-right image, the suitcase in the right-foreground might be able to hold a radiological source and perhaps 100 pounds of lead shielding. The sensitivity measurements made during this project suggest that the ~20-30 feet between the camera and the suitcase would enable a detection for all but the smallest sources, which lack the activity-level to represent a serious threat.

The radioactive Iodine-125 is commonly used in the treatment of cancer patients. Our tests suggest that normal doses of I-125 will not trigger alarms even in extremely close proximity. The main reason for this result is that the radiation from I-125 has a very low energy, and therefore is not very penetrating. Conversely, the Ruthenium/Rhodium source has highly energetic beta particles as its primary release, and these particles interact with intervening molecules to produce X-rays, which are subsequently detected by our system. A caveat worth noting is that the Ruthenium/Rhodium source also emits a very small amount of gamma radiation. Therefore, further study of these types of sources is needed.

The overall conclusions from these field tests are that:

1] False alarms are not routinely produced by ambient radiation levels, even for the much higher background levels found at the Judiciary Square Metro station.

2] Medical procedures that implant radioactive material in patients is unlikely to produce a false alarm.

3] Radiological materials that have any significant degree of capability for causing harm and/or disruption is likely to be detected.

4] Such detections are likely to be highly significant and rapid (less than 30 seconds for multiple rounds of confirmatory detection)

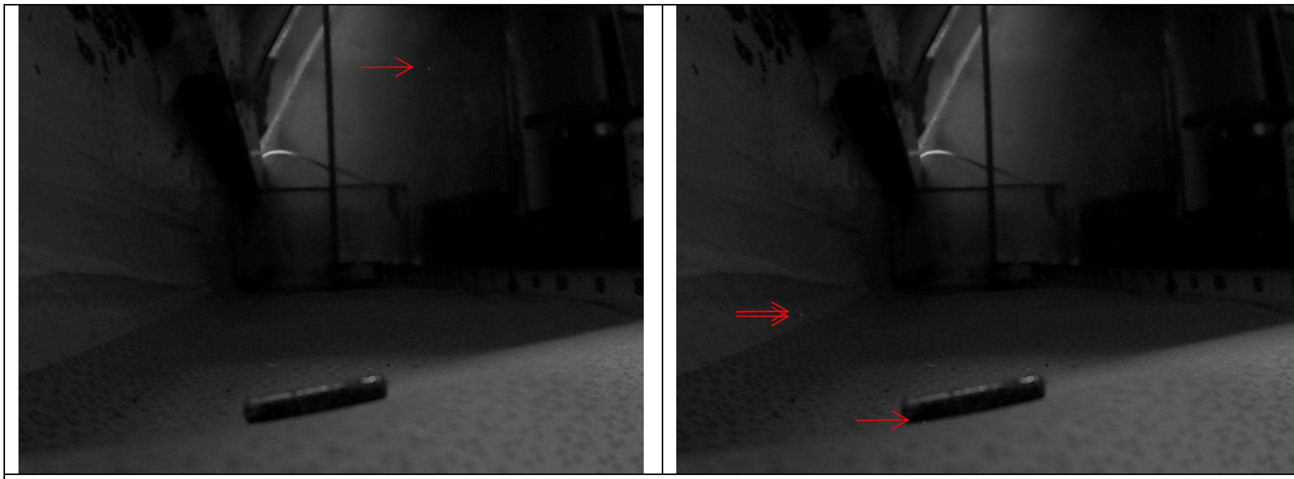

Figure 7: Axis-210 camera images from field test at Memorial Sloan-Kettering Cancer Center. The cylinder in the foreground contains 2.65 mre of Cs-137. The two images were taken approximately 2 seconds apart. The arrows point to the gamma-ray hits on the camera's CCD detector. These events are quantitatively measured by our software, and analyzed to assess if the radiation count-rate is high enough to be considered a threat. Alerts are generated based upon the CONOPS associated with the monitoring site and enforcement authority.

5. PLANS FOR IMPLEMENTATION

AFR has had numerous transit, corporate and government meetings to plan for the commercialization of the RedStar technology. AFR is preparing for a beta-installation at a Washington Metro station, as a first step in deploying the technology. As part of a follow-on project, it is expected that installation will proceed at the Anacostia Metrorail. Future possible transit test sites under discussion are in San Francisco, New York, and Boston. Such installations would be at transit rail stations. Bus stations are also an excellent match to the capabilities and CONOPS by which RedStar technology could be deployed.

Additional activity in other market segments are also under discussion, with sports and entertainment venues the furthest developed. Perhaps the most important contacts are exploratory contacts with a few large defense contractors/prime integrators who have expressed a strong interest in both the technology and the services market that they see growing up around the pervasive-grid radiation detection model. We also believe that the military force-protection market should be explored, but have only begun to do so.

The overall scale of the market opportunity is very large; the U.S. Dept. of Homeland Security (DHS) has identified 100,000 "Critical Infrastructure Sites" and our literature study suggests about 86,000 sites of high economic value. When preparing our business plan, we evaluated the market for radiological detection as arising from several segments. While we plan to pursue the transit market first, Table 3 shows our estimates for the various possible segments.

Table 3: AFR Market Segment Evaluation. Note that some entries correspond to numerous sites (e.g. Metropolitan areas and highways)

Facility	# of Sites
Subway/Metro-rail systems	20
USPS Mail Processing Centers	350
US Skyscrapers > 500 feet high	465
Capitols and Legislative Offices	200
Major US Sports Stadiums and Arenas	290
Major US Exhibition Halls > 50,000 sq. ft.	154
US Malls > 1 million sq. ft.	357
Major Airports and Seaports	100
Theme Parks	230
Major US cities with deployed cameras	50
Highways	50
Toll plazas	2500
Tunnels & Bridges	2500
Factories various industries	50000
Corporate HQ	5000
Police Cars	5000
Oil Refineries	200

AFR will spin-out the development of RedStar technology following the model of its two previously successful launches. This spin-out will continue to develop the technology and will market products both directly and through strategic partnerships with integrators and technology services companies.

By working with WMATA and other potential partners during this project, we have identified a number of technology capabilities that can be incorporated into future product offerings. The technology improvements will be prioritized according to the needs of customers. As we seek to improve the core technology, we are exploring innovative applications that arise. The technical goals for the products embodying our RedStar technology are summarized in Table 4.

Table 4: Project goals

Goal	Objective/threshold	RedStar Approach
Sensitivity enhancement	1-10mCi at 6 feet / 10-100uCi at 6 feet (6-σ confidence)	Combination of improved procedures (factor of 2-4), enhanced algorithms (2-4x better), and larger CCD area and thickness (up to 12x active volume) in initial phase. Another factor of ~100x better in second phase using hardware addition.
Directionality	$\leq 2^\circ$ for high resolution and $\leq 10^\circ$ for man-portable devices	Gradient search via pan-tilt mount will enable direction determination. Precision of direction will depend upon strength of signal. When enough counts exist to detect 10% variations in detected flux, angular discrimination ~ 6˚, if only enough counts to detect 20% variations, angular discrimination ~ 12˚. Larger sources will be better constrained, with angular accuracy improving roughly as the square root of the source activity level
Imagery Integration	Simultaneous Video / coordinated target seeking and video	Matches radiation detection with video images of perpetrator(s)/terrorists for law enforcement and forensics

Distance determination	Precision objective not provided	Triangulation using two or more cameras will constrain source to be within intersection zone of cones that correspond to the directionality precision for each camera.
Interoperability	Communicate over standard networks to other systems	Use of IP network protocols, NIST's XML schema for radiological detection equipment and focus on developing useful CONOPS will yield portable systems.
Isotope determination	We anticipate achieving an energy determination, $\Delta E/E$ of ~8% at 1.33 MeV, based upon our laboratory experiments. Isotopes with multiple lines should be readily identifiable; those with mono-energetic emissions may be more difficult to ascertain, but our planned analyses should provide guidance.	
Package size	Modern digital cameras (webcams/netcams) are small enough to fit in a pocket; networks are pervasive, including wireless ones; computers are shrinking in size and power needs, while growing more capable. The current developmental prototype easily fits in the P.I.'s briefcase. A planned follow-on device with a single-board computer will have a palm-fitting form factor.	
Multiple configurations	Fixed, mobile, and man-portable	The size of cameras and computers, wireless technology and the low power consumption of these components all ensure that each of these configurations is viable.

Probably the most important objective of our near-term future work is to clearly specify the requirements for radiation detection in the transit environment. Our fruitful meetings have identified many of these requirements, but have not yet produced the detailed answers to questions such as:

What does the desired product look like and how does it act during both alerts and non-alert states?

What is the CONOPS that defines the nature of, and information within alerts?

Is it desired that the alerts use the National Institute of Standards and Technology (NIST)-defined schema for radiological alerts so as to enhance interoperability? A separate appendix has an example of this XML data package.

What minimum level of radioactivity should be reported? Is it the same from site to site?

There are many more questions, and as we work out answers more questions may arise. We therefore look forward to working very closely with WMATA and other transit partners as we proceed to develop and deploy RedStar technology and products.

6. CONCLUSIONS

All tasks for this Transit IDEA project have been successful. The ERP was established; several meetings in Connecticut, Virginia, Washington D.C., and teleconferences were conducted. These meetings provided valuable feedback for transit concerns, and greatly enhanced the technical development. One especially important recommendation was that nominal operational feedback to security personnel should be minimal *unless/until* an alert is issued, in which case specific recommended actions should be presented to the NOC operator. Such recommendations for the development of a comprehensive concept of operations will be further developed by the appropriate jurisdictions and communicated to the development team as RedStar technology is considered for rail rapid transit security.

The technical development included integrating a video stream into the single-image oriented analysis algorithms. LiveWave provided initial technical assistance in this area, and their API was built into the prototype eventually tested at Sloan-Kettering. This development streamlines the acquisition and analysis procedure so that images can be evaluated at the maximum-rate possible given current network and computer limitations.

The initial prototype was used in the lab to determine the system's sensitivity. These early results demonstrate that the system can easily detect a 10-100 Ci source at a range of 10-15 meters, within 15 seconds, and probably much faster. A radioactive source with this amount of activity is considered extremely powerful, but is only 0.1% - 1% of the size that the Federation of American Scientists has considered in their threat scenarios. In other words, the sensitivity analyses carried out so far suggest that this system, if broadly deployed, will be able to detect dangerous radioactive sources, but not detect so-called "nuisance" sources, such as patients treated with radioactive medicines and dyes.

As planned during the 18 April 2005 ERP meeting, we collected operational data both at a WMATA and at a third-party facility. For the first test, performed on 18 May 2005, we collected video data from the Union Station and Judiciary Square Metro stations. This data set was used to see if the background radiation-level in the stations will be a source of nuisance alerts; it was not. The second test involved evaluating performance at greater distances using larger radioactive sources in a carefully controlled laboratory environment to measure "real world" sensitivity; that work is reported above, and was extremely successful.

7. INVESTIGATOR PROFILE

Principal Investigator: Eric P Rubenstein, Ph. D., Advanced Fuel Research, Inc. (AFR)

87 Church Street, East Hartford, CT 06108-3728, ericr@AFRinc.com Telephone: (860) 528-9806, ext. 112, Fax: (860) 528-0648

Dr. Rubenstein got a Ph. D. in Astrophysics from Yale University in 1997 and a B.S. in Astrophysics from Columbia University in 1987. While on the faculty at Yale Univ. and Smith College, he specialized in low signal-to-noise, hyper-spectral, time-series data. Dr. Rubenstein has worked on image analysis projects since 1985, during which time he contributed to searches for supernovae and extra-solar planets, stellar population studies and discovered the second largest trans-Neptunian asteroid known at the time. These activities involved extensive experimentation with image analysis techniques. Dr. Rubenstein also has extensive experience in numerical modeling and simulation, Monte Carlo techniques, and hyper-spectral analysis. He has published 40 papers in these areas including references 5–19. Dr. Rubenstein has also worked on neutral lithium beam accelerator and superconductivity experiments involving high-voltage, high-inductance, and cryogenic equipment [20]. Since joining AFR, Dr. Rubenstein has worked on a number of scientific projects and has become the Senior Investigator of a DOE phase II study applying microporous carbon materials to the development and commercialization of ultracapacitor electrodes for high-power applications. The carbon material development work will build upon his recent work on energy storage technology for spacecraft and spacesuits that incorporate radiation shielding [21]. Earlier work on high-energy outbursts on Sun-like stars and their effects on life [22] led to an invited review to *American Scientist* [23]. In addition to being employed by AFR (2002 – present), Dr. Rubenstein is a U.S. Naval Reserve Officer (2002 – present) in the Office of Naval Research (ONR 107). Prior to AFR, he was at Smith College Astronomy Dept. as Assistant Professor, 2001-2002; Yale University Astronomy Dept. as Lecturer, 2000-2001, Post-doctoral Associate 1997-1999 and Cerro-Tololo Interamerican Observatory, La Serena, Chile – Post-doctoral Fellow 1999-2000. Other notable accomplishments are as follows: SYNERGISTIC ACTIVITIES: Member of International Astronomical Union (Bio-Astronomy Commission), American Astronomical Society (High Energy Astrophysics Division), Astronomical Society of the Pacific; Invited review for American Scientist, invited colloquium and conference lectures. HONORS: Navy Achievement Medal (2003), NSF International Research Fellow 1999-2001, JW Gibbs Lecturer at Yale Univ. 2000-2001.

Company Information – Advanced Fuel Research, Inc. (AFR) of East Hartford, CT, is a small contract R&D firm founded in 1980. AFR's goal is to pursue R&D in areas with significant commercial potential. AFR's approach to commercialization is through the creation of commercial spin-offs and via technology licensing. In 1991, AFR spun off a manufacturing/sales company, On-Line Technologies, Inc. In April 2001, On-Line Technologies was acquired by MKS Instruments, Inc. (NASDAQ: MKSI) in a merger.

AFR received the 2000 U.S. Small Business Administration's (SBA) Tibbetts Award for achievement in commercializing technology developed in the SBIR program. AFR's SBIR-developed technologies are brought to market either directly by AFR, one of its spin-off firms, or via a collaborative arrangement with another company.

8. GLOSSARY OF TERMS

Table 5: Glossary of Terms

Term	Definition
AFR	Advanced Fuel Research, Inc. –AFR is a small research and development company located in East Hartford, CT
alpha-particles α	Least penetrating type of radiation, comprised of helium nuclei (two protons and two neutrons)
Beta-particles β	Positron emitted during radioactive decay, typically more penetrating than alpha-particles
CCD	Charge Coupled Device –a type of modern digital image sensor. Typically used in more expensive and more demanding applications than CMOS detectors.
Ci	Curie –a common unit of radioactivity source strength. One Ci is a significant amount of radioactivity, but is not so large that if explosively dispersed in a transit station it would represent an immediate health threat.
CMOS	Complementary Metal-Oxide Semi-conductor –a type of modern digital image sensor. Typically used in less expensive and less demanding applications than CCD detectors.
COTS	Commercial Off-the-shelf –a standard item commercially available
ERP	Expert Review Panel
gamma-rays, γ	Most penetrating type of radiation
MCi	Milli-Curie –one thousandth of a Curie (Ci)
Mre	Milli-Radium Equivalent – a measure of radioactivity
NOC	Network Operating Center –location where collected security data are analyzed and logged. RedStar software can run on computers located either in the NOC or in individual stations.
Radiation	Energetic particles emitted from unstable atomic nuclei. Specific types include: alpha-particles (α), beta-particles (β), and gamma-rays (γ).
REDSTAR	Radiation Event Detection System: Tracking And Recognition (also RedStar) –Patent Pending system for using digital security cameras and AFR's proprietary software to detect dangerous levels of radioactivity
μCi	Micro-Curie –one millionth of a Curie (Ci)
WMATA	Washington Metropolitan Area Transit Authority –our transit partner
σ	Sigma (e.g. 6-σ) –a level of statistical confidence. 1-σ refers to one standard-deviation.

9. REFERENCES

---

1 "Refining Chandra/ACIS Subpixel Event Repositioning Using a Backside Illuminated CCD Model," By: J. Li, J.H. Kastner, G.Y. Prigozhin, & N.S. Schulz, in The Astrophysical Journal, 590: 586–592, 2003 June 10, 2003.

2 One common unit of radioactivity is the Curie, abbreviated Ci. 1 Ci = 3.7×10^{10} decays/sec; 1 μCi = 3.7×10^{4} decays/sec.

3 M. Levi, R. Nelson, & J. Yassif, of the Federation of American Scientists (FAS) performed an analysis of three different types of radiological dispersal device (RDD, or "Dirty Bomb") attacks. A summary of their research can be found here: http://www.fas.org/faspir/2002/v55n2/dirtybomb.htm

4 Dr. Henry Kelley, President of the Federation of American Scientists (FAS) testified before the Senate Foreign Relations Committee on March 6, 2002 on the threat of radiological attack by terrorist groups. That report is here: http://www.fas.org/ssp/docs/030602-kellytestimony.htm.

5 E.P Rubenstein "The Effect of Stellar Evolution upon Population II Contact Binaries in the Period-Color Relation I. Equal-Mass, Marginal Contact Systems," The Astronomical Journal, 2001,121,3219

6 E.P. Rubenstein & C.D. Bailyn: HST Observations of the Central-Cusp Globular Cluster NGC 6752. The Effect of Binary Stars on the Luminosity Function in the Core, *Astrophysical Jrnl (Lett)*, 1999, 513, L33.

7 C.D. Bailyn, E.P. Rubenstein, S.D. Slavin, H. Cohn, P. Lugger, A.M. Cool, & J.E. Grindlay: HST Observations of the Post Core-Collapse Globular Cluster NGC 6752. I: Discovery of Two CataclysmicVariables in *The Astrophysical Journal (Letters)*, 1996, 473, L31.

8 E.P. Rubenstein & C.D. Bailyn: HST Observations of the Post Core-Collapse Globular Cluster NGC 6752. II: A Large Main Sequence Binary Population in *The Astrophysical Journal*, 1997, 474, 701.

9 E.P. Rubenstein & C.D. Bailyn: A W UMa Contact Variable in the Globular Cluster NGC 6397 in *The Astronomical Journal*, 1996, 111, 260.

10 E.P. Rubenstein, "The Search for Main Sequence Binary Stars in Galactic Globular Clusters," 1997, Ph. D. Thesis, Yale University.

11 C.D. Bailyn, E.P. Rubenstein, A. Sarajedini & R. Mendez, "Groundbased Photometry of Nearby Cluster Cores," 1993, *ASP Conf. Series 50: Structure and Dynamics of Globular Clusters*, 227

12 E.P. Rubenstein & C.D. Bailyn, "Variability in the Globular Cluster NGC 6397," 1992, *Bulletin of the American Astronomical Society*, 24, 1241

13 D. Tytler & E.P. Rubenstein, "High Resolution Optical Spectra of 120 White Dwarfs," 1989, *International Astronomical Union Colloquium 114: White Dwarfs*, 524

14 Clocchiatti, ... E.P. Rubenstein, ...et al.: "The luminous type Ic SN 1992ar at z=0.145," *The Astrophysical Journal*, 2000, 529, 661

15 M. Hamuy, ...E.P. Rubenstein, ...et al.: “BVRI Light Curves for 29 Type Ia Supernovae” in *The Astronomical Journal*, 1996, 112, 2408

16 C.D. Bailyn, E.P. Rubenstein, T. Girard, D. Dinescu, F. Rasio, & B. Yanny: “A Possible Optical Counterpart for the Triple Pulsar System PSR B1620-26” *The Astrophysical Journal Letters* 1994, 433, 89

17 E.P. Rubenstein, J. Patterson & J.L. Africano: “The Orbital Period Changes of UX Ursae Majoris” in *Publications of the Astronomical Society of the Pacific*, 1991, 103, 1258

18 K. Krisciunas, N.B. Suntzeff, M.M. Phillips, … E.P. Rubenstein, et al.: “Optical and Infrared Photometry of the Nearby Type Ia Supernovae 1999ek, 2001bt, 2001cn, 2001cz, and 2002bo”, submitted 2004.

19 E. Tousson, V. Volterra, E.P. Rubenstein, R. Rosenbaum & Z. Ovadyahu: “A Shift in the Mobility Edge at Weak Magnetic Fields” in *Philosophical Magazine B: Physics of Condensed Matter Structural, Electronic, Optical and Magnetic Properties*, 1987, 56, 875

20 E. Tousson, V. Volterra, E.P. Rubenstein, R. Rosenbaum & Z. Ovadyahu: “A Shift in the Mobility Edge at Weak Magnetic Fields” in *Philosophical Magazine B: Physics of Condensed Matter Structural, Electronic, Optical and Magnetic Properties*, 1987, **56**, 875.

21 E.P. Rubenstein, M.A. Wójtowicz, E. Florczak, E. Kroo, M.A. Serio, August 2003, NASA SBIR Phase I Final Report, “Microporous Carbon for Radiation Shielding and Hydrogen Storage,” Contract NAS1-03030.

22 E.P. Rubenstein & B. Schaefer: Are superflares on solar analogues caused by extra-solar planets? in *The Astrophysical Journal*, 2000, 529, 1031.

23 E.P. Rubenstein: Superflares and Giant Planets, in *American Scientist* January/February 2001