# VI. Three Exemplary CRADAs

## EVALUATION OF ELECTRON CYCLOTRON RESONANCE PLASMA TECHNOLOGY

*Addresses Warfighting Needs, Strengthens the Industrial Base, Promotes Basic Research, and Assures Quality*

Infrared Focal Plane Arrays (IRFPAs) are critical for use as sensors in tanks, helicopters, remotely piloted vehicles, and missiles. IRFPAs are the artificial retinas present in all infrared cameras mounted in these vehicles. These retinas detect thermal radiation and generate real time images of battlefield objects which are warmer or cooler than their surroundings.

A FPA consists of an array of detector cells on a chip. Each cell is an individual sensor pixel. An image is formed by an array in the same way that an image is formed by the charge-coupled device (CCD) in visible cameras. However, unlike CCDs, FPAs operate at infrared wavelengths. IR systems use different types of IR materials in the detector, depending on the level of performance and applications required.[30] The infrared material used in the highest performance IRFPAs, which are sensitive in the 3 - 5 and 8 - 17 micron region of the infrared spectrum, are made of mercury cadmium telluride (HgCdTe), a member of the semiconductor family of materials. An array is synthesized by depositing thin films of HgCdTe onto rigid substrates. These planar layers must be transformed into electrically isolated pixels, the analog of the rods and cones of the human retina. For fifteen years, the industrial baseline process for producing focal pane arrays with mercury cadmium telluride has been to form mesas and trenches in the layers by dipping them into a liquid chemical etchant. All second generation focal plane arrays are manufactured with this technology. To obtain adequate signal to noise ratios for HgCdTe arrays, they must be cooled to temperatures as low as -200°C. The apparatus required for this cooling adds cost and complexity to an IRFPA. At this time, due in part to their cost, the main end user of high performance IRFPAs is the military.

Although the military market is the largest end-user of IR systems, a growing commercial market exists, and is expected to be substantial by the end of the 1990s and into the next century. In 1994, total revenues from U.S. military and commercial consumption were $658.7 million. In 2001, revenues are projected to swell to about $1.45 billion, largely a result of significant increases in commercial applications stemming from new IR materials.[31]

Army requirements for higher standoff distances and target recognition capability have led to concepts for the next generation of arrays which will have a much higher pixel count than is present in the current generation. To keep the cooling requirement at a manageable level, the size of individual pixels will be reduced to minimize the overall size of an array. The largest FPA produced so far is an array of 1,024 pixels by 1,024 pixels, 1024 x 1024 technology is in a very early stage of the development cycle and only a few prototypes this large have been made.

To transform a planar film of HgCdTe into an array of isolated pixels, HgCdTe materials must be etched away from between each pixel and its neighbor. A barrier problem to fabricating larger arrays with smaller pixels is rooted in the isotropic nature of the wet chemical etching procedure which is now used to remove this material. Material is removed as rapidly along the surface of the wafer as it is in a direction perpendicular to the surface. The widths of trenches are too great for next generation arrays.

In 1993, the U.S. Army Communications and Electronics Research, Development and Engineering Center, Night Vision and Electronic Sensors Directorate, (NVESD) anticipated the need for small feature widths and along with several university and industrial laboratories, made a decision to explore the suitability of a new vapor phase etching process - Electron Cyclotron Resonance (ECR) etching - as a potential replacement for liquid phase etching. The approach would be to insert a masked HgCdTe film into an ECR vacuum system, to expose it to gases such as argon and hydrogen, and to thereby transfer the required pixel pattern through the mask into the HgCdTe by the action of these reactive gases. NVESD purchased a state of the art ECR reactor and initiated an internal program to develop this technology.

Along with NVESD, the Defense Research Projects Agency (DARPA) has dedicated substantial funding to establishing a production capability for common and universal second-generation FPAs. In 1993, DARPA initiated a program known as Flexible Manufacturing whose aim it was to make mercury cadmium telluride focal planes available and affordable to the military. The approach was to develop high yield manufacturing processes for this material. A small ECR etching effort, principally at Loral and at Texas Instruments (TI), was funded under this program.

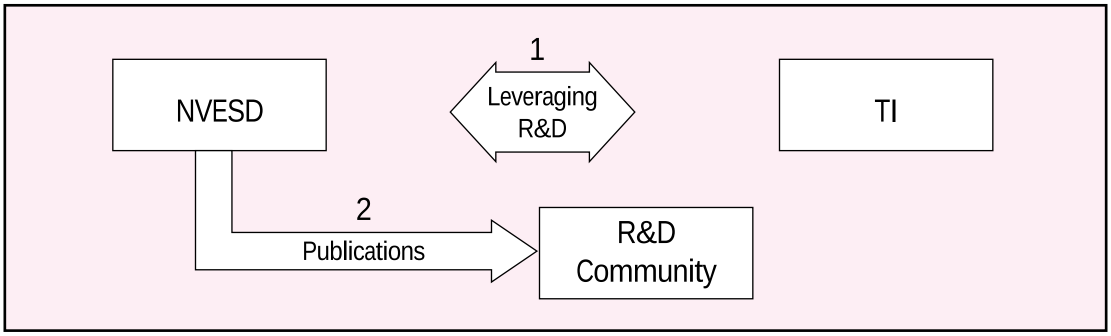
In 1996, TI hired a scientist who had studied plasma etching as a university student and who had published results of great interest to the scientists within NVESD who were involved in the ECR effort. NVESD contacted this scientist to discuss status of ECR programs at TI and at NVESD. It became evident during a series of visits and discussions that each organization had strengths which perfectly complemented those of the other. A CRADA was then negotiated to develop a working relationship to take advantage of these strengths in order to further the development of the next generation of focal plane arrays. In the CRADA it was agreed that TI would contribute the very high quality and many-layered mercury cadmium telluride samples which they routinely make. NVESD would then etch samples of these in its ECR plasma etching apparatus. TI would then measure electrical and structural properties of the etched layers to assess suitability for the TI device architecture.

After one year the etching process looks promising. A few milestones towards developing the next generation FPA have been achieved. The etching process produced an FPA 128 pixels by 128 pixels with each pixel being 24 microns by 24 microns. TI has now purchased a plasma reactor in order to continue the research effort and will eventually integrate this technology into their future production line.

Given that the largest FPA made by existing methods is 1024 pixels by 1024 pixels, more milestones have yet to be met on the road to developing the next generation FPA. Future challenges include:

- Developing a process whereby all electrical characteristics of the HgCdTe film are preserved during etching (at the present time, certain electrical characteristics change);
- Developing a process whereby very small features such as narrow trenches and small-area mesas can be formed by ECR etching;
- Developing a process for making very large focal plane arrays on the order of 2cm x 2cm;
- Developing an ECR process which is carried out under real-time control (an operator would set the final etch depth and an automated control system would take over to monitor the depth and turn off the etching when the target depth had been reached).

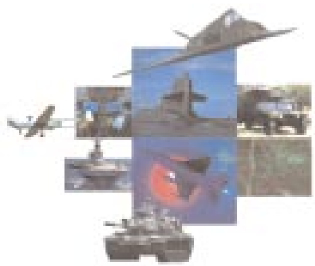
This CRADA advanced the knowledge necessary for the future production of next generation focal plane arrays in which the pixels are smaller and closer together. Although no joint research papers have been published at this time, NVESD has published some results of the progress in developing the plasma etching technique. These publications include "An a-Si:H Vacuum Compatible Photoresist Process for Fabricating Device Structures in HgCdTe," Journal of Electronic Materials, 27 (1998) 689 and "Spectroscopic Ellipsometry study of HgCdTe Epilayer Surfaces During ECR Plasma Etching," Materials Research Society Symposium Proceedings, 450 (1997) 293.




*CRADA Value Flow Diagram*

## CRADA BETWEEN THE NAVAL TRAINING SYSTEMS CENTER* AND THE COMPUTER GROUP OF MOTOROLA, INC.

*Addresses Warfighter Needs, Reduces Cost and Promotes Basic Research*



*"The CRADA gave us the learning experience to get up to speed on DIS. It gave us the knowledge and the experience to be successful," says Motorola's Ralph Whitney.*

In today's digital age, realistic simulations of complex battlefield scenarios and mission training of large distributed teams are becoming vital in contributing to the superiority enjoyed by the Unites States armed forces. Technology development efforts underlying these simulation capabilities are therefore important to the overall DoD mission.

Distributed Interactive Simulation (DIS) technology provides an infrastructure to build large scale simulations of highly interactive activities by interconnecting several types of simulators via a network. It brings together systems built for separate purposes — technologies from different eras, products from various vendors, and platforms from various services — and permits them to be interoperable in a synthetic, virtual environment. Appropriate protocols, simulation managers and visualization software products are among the many key underlying technological components which make DIS successful. Applications of DIS include distributed mission training, analysis, acquisition, entertainment, education and research.

In FY95 the Naval Air Warfare Center, Training Systems Division (NAWCTSD), and the Computer Group of Motorola, Inc., entered into a CRADA leading to the development of three important DIS tools. The objective of the CRADA was to gain experience with the new DIS interoperability standard through jointly developing software to support networking of simulators using DIS. The knowledge-share CRADA ended in FY97. About one man year of effort over a three year period was input from the government while Motorola contributed staff and expertise.

Three products resulted from this CRADA partnership: Middleman, Aladdin and Daemon. The development of these products was a by-product of the original intent that was to gain experience with the interoperability standard. The development of each of these software products was a unique, one-of-a-kind effort. Since Motorola does not hold intellectual property rights to the software, these products are available to government agencies and their contractors free of charge. The software can be briefly described as follows:

- Middle Man is a DIS simulation manager whose job it is to automatically and dynamically initialize and control DIS exercises.
- Aladdin is a DIS Stealth Viewer that allows the user to attach to any entity (such as a boa or a tank) in a DIS exercise and view the entity from any orientation. It provides several view modes and visual control mechanisms.
- Daemon is a DIS Network Interface Unit. The DIS Daemon is being used on a number of DIS programs ensuring stability and reliability under real world conditions. It helps in providing flexible and scalable architecture for DIS applications.

This CRADA effort allowed the NAWCTSD to leverage Motorola's software development expertise and Motorola to further their knowledge in military simulations. In addition, the experience has also allowed NAWCTSD staff to function as a "smart buyer" whereby their research team is up to date with the technology, thus allowing for more educated purchases.

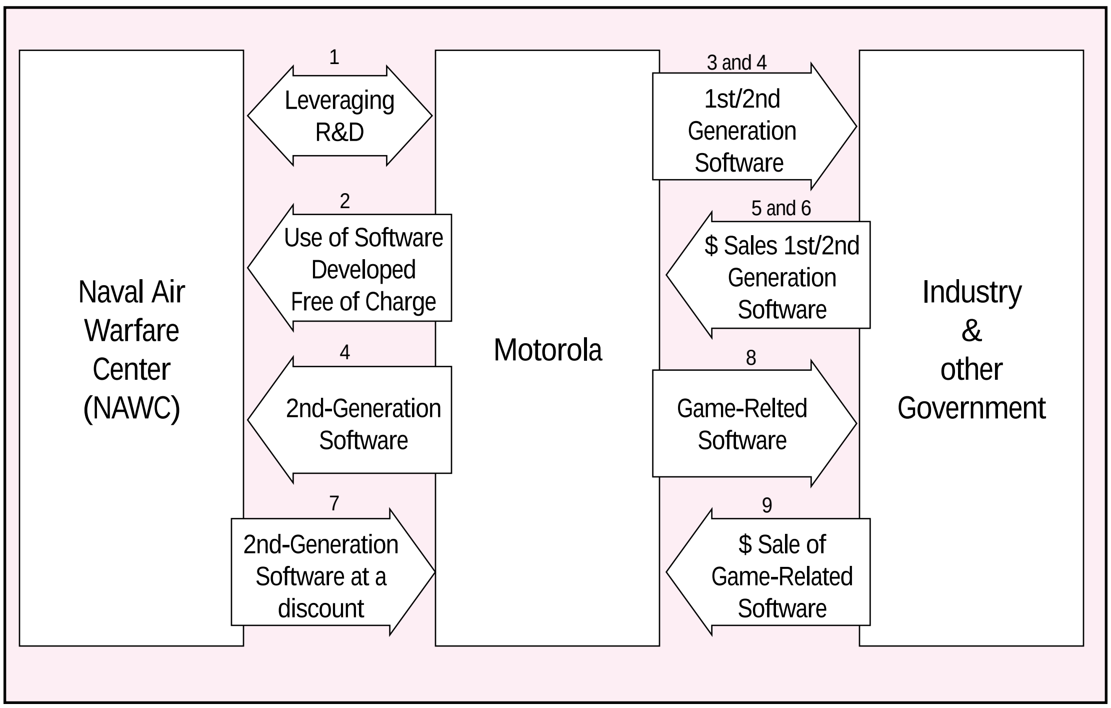
**Now known as the Naval Air Warfare Center, Training Systems Division*

The two partners jointly demonstrated the DIS technology at the annual IITSEC (Inter-Service Industry Training Systems and Education Conference) show, which is one of the biggest shows in the training and simulation area.

DIS technology is used by many DoD agencies, including the Naval Research Laboratory, the U.S. Army Soldier Systems Command, and the Night Vision and Electronics Sensors Directorate. One application of its use is the annual ULCHI FOCUS exercise in Korea, which is an annual large-scale mission training exercise. The DIS tools developed in the CRADA are also embedded in the electronic warfare LAN access unit of the Battleforce Tactical Trainer (NAVSEA).

This CRADA provided the springboard for Motorola to enter the DIS-related software market. Motorola has internally developed a second-generation software called MODIAS that is indirectly linked to the work performed under the CRADA. The second-generation products are available to the government at a 40 percent discount.

Motorola is distributing the three DIS developed software tools at no charge and making a profit by providing the support services to these products. The commercial application for DIS is in the gaming industry. The sales of the software associated with the gaming industry applications are estimated to be $1M.




*CRADA Value Flow Diagram*

## HAZARDOUS MATERIALS MANAGEMENT SYSTEM

*Reduces Cost and Strengthens the Industrial Base*

**LINDEN™**
**Environmental Management System**

The U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate (AFRL/ML), uses more than 10,000 different chemicals in over 40,000 containers in its 15 facilities. This level of activity and complexity necessitates a very aggressive pollution prevention program to assure that health and safety are a top priority and that environmental issues are correctly managed.

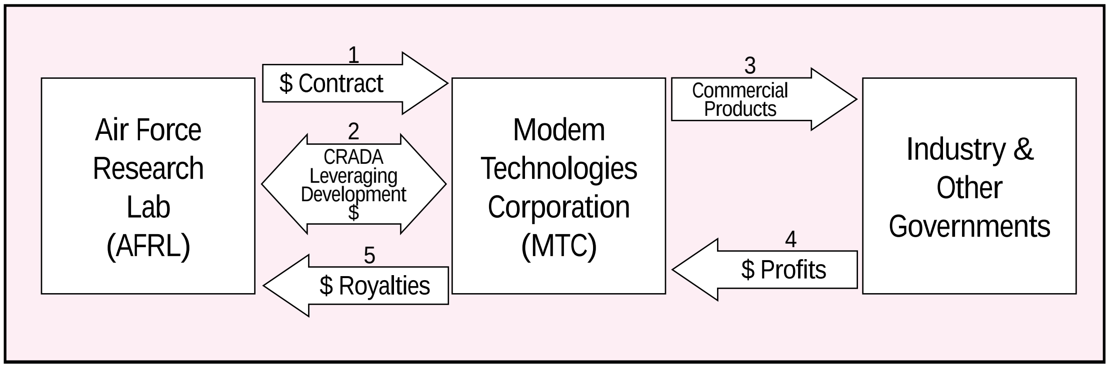
In an effort spearheaded by the Assistant Chief of Integration and Operations Division, AFRL and driven by new environmental regulations for strict regulatory compliance, the AFRL/ML in cooperation with Modern Technologies Corporation, worked together through a contract to develop a software system using bar code technology to coordinate the tracking and control of hazardous materials. With the intention to commercialize the system, a CRADA was then negotiated to use the AFRL/ML, then Wright Laboratory, as a Beta test site for the computerized environmental management system.

In conducting the Beta test at the Directorate, over 40,000 hazardous materials and waste containers were tracked throughout their complete use life, resulting in purging of over 10,000 hazardous material containers no longer needed by researchers. More than 400 containers of unknown materials were identified, classified and eliminated. In some cases, the effort permitted the identification of replacement chemicals that are less harmful to the environment.

As a result of the feedback received from the Beta test site, the industrial partner was able to further develop and commercialize the software system. The original version, the Integrated Materials Management System (IMMS), now commercially known as the LINDEN™ Environmental Management System (LINDEN™) is a Microsoft Windows™ application on a single PC or PC network. LINDEN™ enables effective centralized hazardous materials management, waste minimization and pollution prevention, reduction in materials costs, and prevention of materials shortages through more effective control and retrieval. The system has the capability to flag and report expired or unstable materials and storage of incompatible hazard classes. On-Line access to full-text Materials Safety Data Sheets allows users immediate access to information on the hazards of a material or product. LINDEN™ can produce environmental reporting to satisfy the requirements of SARA Title III, including Tier I and Tier II reports, as well as emissions summary reports to assist with completion of the Toxic Release Inventory (Form R) report and Clean Air Act Title V reporting. The Hazardous Waste Manifest and Land Ban Module, a component of the now upgraded LINDEN™ system, provides manifest generation and tracking, land disposal restriction notification, and annual/biennial reporting. The LINDEN™ system contains a tremendous amount of pre-loaded data needed for all facilities to develop data for special reports that can be influential in identifying pollution and waste minimization opportunities. This data includes: U.S. DoT tables, U.S. EPA List of Lists, SARA storage conditions and container types, and crucial information for over 74,000 CAS chemicals. Using system data, the storage of hazardous chemicals is consolidated, helping to eliminate duplicate and excess stock.

The development and use of the LINDEN™ system has truly been a success in reducing costs and preventing potential fines associated with the strict hazardous materials regulatory compliance initiatives. The value in using the LINDEN™ system to reliably manage the hazardous materials program at the AFRL/ML is conservatively estimated by the Air Force to be $10K in terms of equivalent contracting costs. By incorporating the LINDEN™ system, the AFRL has saved significant materials and waste disposal costs as well as labor hours that would have typically been spent on documentation and tracking. The LINDEN™ system was at the core of the AFRL, Materials Directorate, winning the 1995 Ohio's Governor's Award for Outstanding Achievement in Pollution Prevention.

In keeping with the intent of the technology transfer law, this CRADA produced a commercialized product that was transferred into the marketplace and is now available for both government and industry use. More recently, Modern Technologies has produced a more advanced upgraded system with additional functionality and a web interface. Now that the software has been upgraded, the AFRL is no longer eligible for royalties. However, Modern Technologies Corporations sells the enhanced LINDEN™ system at a discount to government agencies. At least $100K in software has been installed at government installations such as the Center for Disease Prevention and Control, Atlanta, GA and the Army Redstone Arsenal in Huntsville, AL. The LINDEN™ system has also been sold to aerospace and manufacturing industries, such as Delta Airlines and Cincinnati Milacron, where the Air Force received $4K in royalties.




*CRADA Value Flow Diagram*