General Bernard Schriever and General James Abrahamson

Partnerships with the Air Force Materials Laboratory

General Schriever and Gen. Abe became well-known figures worldwide - well beyond their fame in the Air Force. General Schriever's prominence was in the late 1950s into the 60s while that of Gen. Abe's was in the 70s and 80s.

The Air Force Materials Laboratory developed direct partnerships with both these most famous Air Force generals of the modern era when the Laboratory was given the opportunity to tell them directly about new technologies which turned out to be vital for the ballistic missile and laser defense systems they were building. The systems in place today continue to rely on these same technologies.

The US ICBM program started in 1954 by B/Gen. Schriever had encountered performance limiting roadblocks by the early 1960s both in the re-entry systems and in the launch rockets. The Materials Laboratory offered two different types of composite materials to directly address the issues: new high temperature thermal protection composites and new structural composites. Both these technologies were successful and remain in the ICBMs operating today.

Gen. Abrahamson's introduction to the Materials Laboratory was in two different arenas. As the first director of the F-16 fighter program in 1978 he chose an ML ManTech expert as his director of manufacturing; he also relied on ML sustainment experts to assure long service life for the thousands of F-16s eventually produced. Second, when he became director of President Reagan's SDI program in 1983 he called on the Materials Laboratory to provide key design information on high energy laser weapons and the on technologies required to protect US systems from laser threats.

Remarkably some of the most important materials technologies for these quite different weapons systems arenas were the same. High temperature system engineering tools developed by ML for ICBM thermal protection were also used directly in high energy laser system design. ICBM strategic surveillance/early warning systems use ML optical filters for protection from laser weapons threats. The ICBM strategic surveillance satellite systems were eventually incorporated in the SDI-MDA systems. The infrared sensors for these systems were originally developed in ML under the leadership of Bill Fredericks who later became MDA chief scientist.

The ML Partnership with Gen. Schriver: The US ICBM Program

A prominent Air Force historian, T. C. Lin noted in 2003 that: *'…… the ICBM program has been one of the most successful programs in the history of the Department of Defense'* specifically highlighting composite materials and high temperature thermal protection systems (TPS) as two of the three most important technology arenas. The Materials Laboratory has been explicitly acknowledged as a major contributor in both these arenas.

Gen Schriever's introduction to advanced composites was based on very successful boron fiber composites programs ML conducted with Texaco Corp. In 1963 briefings made by George Peterson and the ML team he noted that continuous boron fiber was *"the greatest breakthrough in materials in the last 3000 years*". He immediately established new AF programs in the structural composites arena which

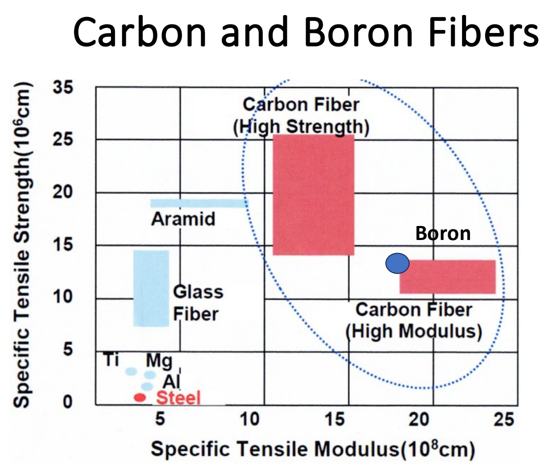
ML lead for more than 3 decades. The high temperature thermal protection composites arena was distinctly different than the structural composites and the Materials Laboratory made even more unique and important contributions in this arena.

Father of the US ICBM System Research

Presenting the ML Award *1963*

The AF Materials Laboratory Symposium *1965*

Both of these composite materials arenas changed dramatically in 1963 when carbon and graphite fibers emerged nearly simultaneously in Europe, Japan and the US. With at least 10x the strength and stiffness of other fibers available at the time a vast array of different fibers became available with key properties tailorable to specific applications. Boron fibers, while extraordinary as noted by Gen Schriever, represented just one point on the graphite/carbon fiber opportunity map.



It's not an overstatement to assert that carbon/graphite fibers changed the world. These fibers were quickly introduced into sporting equipment (tennis rackets, skis, bicycles, golf clubs), electronics, auto bodies and civilian and military aircraft. In the thermal protection arena, the 'BC' era – before carbon fibers - ended in 1963 as the entire community pivoted to carbon fiber-based composites. For thermal protection applications carbon fibers offered the only route to realize the full capability of the ultimate ablator for hypersonic ballistic re-entry – graphite. To strengthen monolithic graphite, carbon fibers were introduced in the form of a reinforcing matrix - an all-carbon composite – 'carbon/carbon. This proved the best TPS option by far for high precision hypersonic re-entry. NASA called these new composites RCC – reinforced carbon composites; the AF and others referred to them as CCC or simply C/C.

Structural Composites: There were commercial and military initiatives worldwide to introduce carbon/graphite-based composites into new products and Gen. Schriever's selection of ML to lead the Air Force programs proved very important. The director of these programs, George Peterson was soon recognized throughout the DoD, the United States and internationally for his advanced composites leadership. Because there were so many different commercial and military composites initiatives his challenge was not only leading Air Force programming but effectively leveraging other programs both in the US and internationally. His election to the National Academy of Engineering and posthumous induction into the National Engineering Hall of Fame in 2021 formally recognized his contributions.

George Peterson

Dr. Steve Tsai

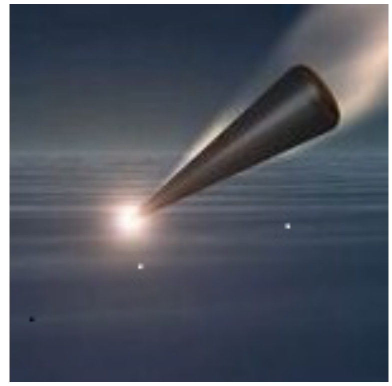
Dr. Nick Pagano

He clearly understood that engineering design of advanced structural composites was a much greater challenge than established structural design with monolithic metallic alloys. He chose Dr. Steve Tsai, an internationally recognized mechanics of composites expert and member of the National Academy of Engineering, as the ML chief scientist. Dr. Tsai was joined by Dr. Jim Whitney and Nick Pagano to build the necessary mechanics of composites analyses tools and a national network of journals and conferences for this new community. Dr. Pagano was recognized internationally for his important contributions and was elected to the National Engineering Hall of Fame in 2023.

While most of the initial Air Force applications were for composite aircraft structure, the US ICBM program was an immediate beneficiary as well. Very large diameter launch rocket motors required both very high strength as well as high stiffness (modulus). Carbon/graphite fibers were incorporated in both solid rocket and liquid rocket components.

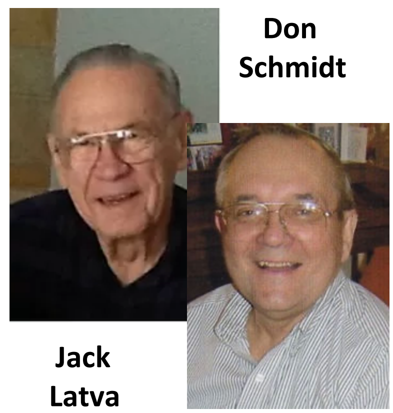
Thermal Protection System Composites. The leading aerodynamic expert of the time, Theodore von Karman, described the re-entry problem, re-entering the atmosphere at speed of Mach 12-20 (velocities up to ~ 23,000 ft/sec) as '*perhaps one of the most difficult problems one can imagine'*. Remarkably NASA with important help from the AF essentially solving the manned ballistic re-entry problem by about 1965 with the successful Mercury, Gemini and Apollo programs. ICBM ballistic re-entry, however, required a different thermal protection solution which remained unsolved. For re-entry vehicle accuracy and survivability ICBM systems required a very sharp nose tip configuration rather than the Mercury/Gemini/Appollo 'blunt body' configuration. Experts at the time noted that

'*for a sharply pointed body the shock wave would remain attached to the tip causing extreme heating and destruction of the body*'.



The only potential solution was graphite reinforced with the new high-performance graphite/carbon fibers. The Materials Laboratory launched two parallel complimentary technology initiatives to address this challenge: 1) major TPS materials programs with industry to produce high strength/high density C/C composites and 2) multifaceted thermal systems engineering design programs which included both ML in-house and industry elements.

The composite development program was led by Don Schmidt and Rex Farmer in the Non-metallic Materials Division. This team had several prior years of experience in ablative plastics including working with LTV which had made the key discoveries leading to C/C composite development. Their successful composite development programs with industry extended more than two decades. The expertise, dedication and accomplishment of this ML team was acknowledged by the entire composites community. In their centennial of flight commemoration, the Society for the Advancement of Materials and Processes Engineering chose Don on of the nation's outstanding 'Pioneers and Innovators'.



Don Schmidt

Jack Latva

For rocket applications, C/C developments were managed by Jack Latva in the Metals and Ceramics Division. The emphasis was on manufacturing technology because the main TPS issue was establishing practical and cost effect ways of producing large complex rocket motor components. Jack led the ML composite development and ManTech programs. His collaborations with the AF Rocket Propulsion Laboratory at Edwards AFB were the basis of the effective industry partnership with the major military and civilian rocket motor system contractors.

The ML thermal system engineering group led by Merrill Merrill Minges and Gary Denman was established by the Chief Scientist, Dr. Al Lovelace, (later the ML director, director of all AF Laboratories and NASA Associate Administrator). Initially the focus of the group was improving the engineering accuracy of very high temperature property information on thermal protection materials. The group quickly established prominence in the arena and Dr. Lovelace expanded its scope internationally through NATO and later the International Council of Scientific Unions. Eventually the high temperature measurement improvement program directed by the thermal group extended to 50 laboratories in 23 countries. The group was recognized with the top international award from this international community in 1983,

Working with the AF Ballistic Missile Division and the ICBM program offices the thermal group developed a four-part series of programs to address the ICBM sharp nose-tip challenge: 1) measurement of C/C composite performance in the high temperature/high pressure plasma arc environment, 2) hypersonic velocity (13- 18,000 ft/sec) ballistic range measurement of C/C performance including visualization of shock layer interactions,3) aerodynamic flow field features of ablated shape models in the hypersonic wind tunnel at the von Karman facility in Belgium (15,000 and 20,000 ft/sec test series, and 4) improving and coupling state of the art hypersonic analytical design tools and tailoring them ICBM applications. For design tool development the thermal group established a partnership with Aerotherm Corporation, well regarded as a leader of many of the most important NASA programs in the arena.

Success of this work included several firsts establishing the thermal group as a 'Trusted agent' for BMD: ML directed testing in the AF Flight Dynamics 50 MW arc facility which validated it as an important and unique national test facility for re-entry and rocket system testing; demonstrating the new capabilities of the AF Test Center ballistic range and the von Karman hypersonic wind tunnels for coupled aerodynamic/materials response tests and analytical modeling and building the initial nonproprietary analytical framework for sharp nose tip configurations fully leveraging many years of NASA programming.

Dr. Gary Denman

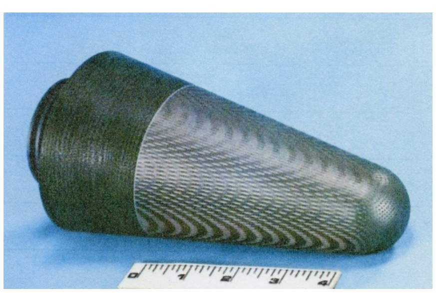
Dr. Merrill Minges

In independent follow-on programs the Ballistic Missile Division systems engineering organization developed and published a comprehensive 23-volume design guide for passive nose tip configurations.

Dr. Al Lovelace
ML Director

The very early relatively blunt and inaccurate re-entry vehicles in Gen. Schriever's program, the Mk 2 and Mk 3/4 weighed between 2500 to 2700 lbs. The later Mk 12/Mk 21 with optimized C/C thermal protection and high efficiency warheads were in the 400 lbs. range. Mk 12/Mk 21 were sufficiently small and high precise that many individual vehicles, up to 12, could be launched at one time. All later and current ICBMs use this MIRV (Multiple Independently Targeted RV) configuration. This same technology remains in place today in the Mark 21 system.

ML Hosted International Thermal Conductivity Conference



Mark 12 Nose Tip

Mark 12 Re-entry Vehicle

Mark 12/Mark 21 MIRVs

The Materials Laboratory contributions in the TPS arena have been formally acknowledged by the aerospace community. The Avco-Textron press releases associated with the fielding of the Mk 12A carbon/carbon nose tip made note of the partnership:

"This nose tip is a 3D Fine Weave Pierced Fabric [FWPF] carbon/carbon material developed under programs sponsored by BMO and the Air Force Materials Laboratory".

Years of experience have shown that any new promising technology requires more than two decades for successful transition to use. It is remarkable that in less than a decade from the emergence of carbon fiber in 1963, the M 12 system became operational in 1972.

Once this milestone had been reached the core of the ML thermal group became the Space and Missile Branch in the System Support Division continuing to serve for over three decades as a trusted agent for BMD. In 1974 Lt. Gen. Dick Saxer, former ML director (1972-74) became the director of the ballistic missile development organization within BMD which Gen. Schriever had established. When Gen. Schriever, as a four-star general became head of the newly formed Air Force Systems Command in the early 1960s, George Peterson established an ML 'West Coast Office' in his Los Angeles headquarters. The WCO remained in operation for over four decades. Directed by Paul Propp, it was one of the most successful of the offices ML co-located in AF space, aircraft, missile and electronics program offices throughout the nation.

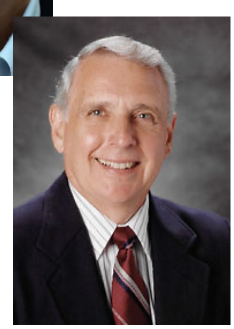
Lt. Gen. Dick Saxer

Paul Propp
ML West Coast Office

The ML partnerships with Gen. Abe

F-16 Program. In 1978 at the very beginning of the F-16 program the first director General Abrahamson chose Dr. Sonny Pierce, the deputy director of the AF ManTech program as director of manufacturing for this new US fighter thousands of which would be eventually deployed worldwide by the US and its allies. The Materials Laboratory had become an established aerospace industry leader directing the entire AF manufacturing program. ManTech hastened the transition to economical systems use of technologies across all the AFRL directorates. Under the initial leadership of George Peterson and subsequently Jim Mattice the program grew to several hundred million dollars annually. Later Dr. Pierce became a manufacturing executive at General Electric and Jim Mattice became the deputy undersecretary of the Air Force responsible for the service's entire science, technology and engineering program. This same position had been held earlier by Dr. Lovelace.

Dr. Sonny Pierce



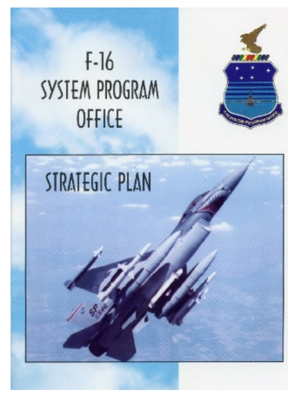
Jim Mattice

Because the F-16 program office was located at WPAFB Gen. Abe was able to reach out to AFRL for expertise in every area important To his program. The unique aircraft maintenance and sustainment expertise of the ML System Support Division was especially important. Once deployed, the most important operational issues were assuring the aircraft were 100% 'mission capability' and that maintenance could be performed quickly, successfully and at reasonable cost both on the flight line and at the F-16 sustainment center in Ogden Utah. The system support director, Walt Conrardy, led the ML team in many intense sustainment discussions with Gen. Abe.

In addition, as the F-16 became widely deployed System Support Division specialists in hydraulics, corrosion, coating and structures Were called upon continuously to assist both the Ogden sustainment center and directly on the flight line in operational locations worldwide.

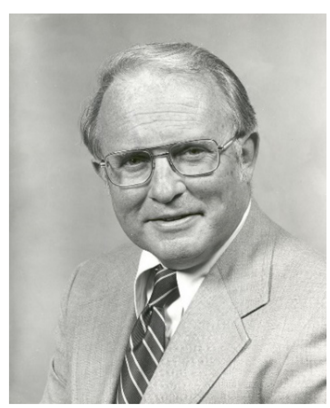
Walt Conrardy

By the early 90s when Dr. Minges became F-16 technical director, the program office was well established with a staff of ~ 1600 at WP managing US and international production and upgrades of operational aircraft, at Ogden Air Logistics Center managing sustainment and at San Antonio Air Logistics Center working directly with the commander, Maj. Gen Lew Curtis managing F-16 turbine engine development and sustainment. The principal challenges at the time were providing specific recommendation on aircraft modification and upgrade programs critical to Air Combat Command combat to assure readiness for Gulf War/Southern Watch & Bosnia War operations. Even though the mods/upgrade budget was several billion dollars annually, only the highest priority issues could be addressed.



During this period the international productions programs were growing as well especially the new Japanese F-16. Dr. Minges managed the F-16 Strategic Plan initiative capturing the program office big picture on US and international programming.

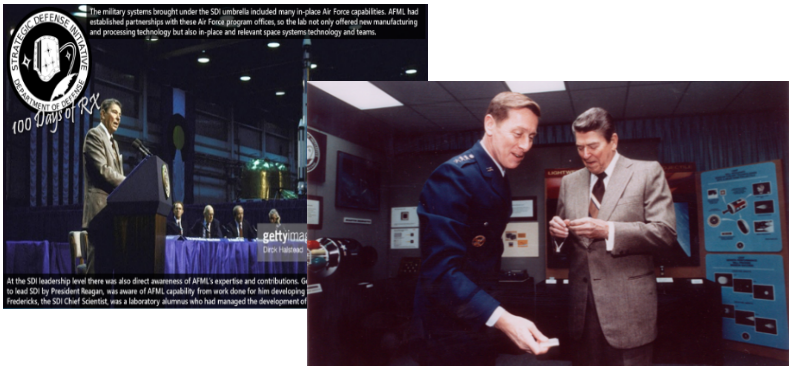
NASA. When Gen. Abe became NASA Associate Administrator as the Space Shuttle director in 1981, former ML director Dr. Al Lovelace was serving an Deputy Administrator for the entire agency. Prior to his NASA appointment Dr. Lovelace served as direct of science and technology at AFSC headquarters and then principal deputy Air Force Secretary responsible for the entire AF research and development program.



NASA Associate Administrators

1981

Missile Defense. When Gen. Abe became director of President Reagan's 'Star Wars' program in 1983 one of the principal potential weapons families beginning considered was high energy lasers. The most important initial design questions were: 1) how energetic do these beams have to be and how long the illumination to kill the target - the key offense 'lethality' question and 2) if US systems were exposed to similar enemy laser weapons how these assets can be protected from this threat – how do we 'harden' US systems so they survive - the key defense 'vulnerability/survivability' question.



In the early 1970s well before the beginning of SDI, the use of lasers as weapons was being widely evaluated so the Materials Laboratory began programs to answer these specific questions precisely and accurately. The ML thermal team knew that the powerful design and analysis tools developed for ICBM TPS systems could be easily adapted to evaluate the thermal effects of high energy lasers. Integral to laser effects evaluation was building a new laboratory equipped with different laser devices covering a wide range of threat laser energies and optical wavelengths. Once the laboratory and initial modeling capability was in place Dr. Gary Denman formed a partnership with the AF Weapons Laboratory which was leading AF efforts to develop laser weapons. Air Force system program offices were also made aware of this ML capability as they began their assessment of laser vulnerability. Space systems were considered especially susceptible to these threats as were manned systems such as combat aircraft.

Maj. Gen. Don Lamberson (then Col.) was the chief of the high energy laser program at the Weapons Laboratory when he and Dr. Denman formed this natural and effective partnership. From WL, General Lamberson was soon promoted to the position of DoD undersecretary of Defense for directed energy weapons. His advocacy at the national level of Air Force expertise in the missile defense arena included describing the potential contributions of the Materials Laboratory. The importance and uniqueness of ML expertise led to new funding for the high energy laser effects facilities at WPAFB – the Laser Hardening Materials Evaluation Laboratory - LHMEL. DARPA was also an important partner and a long-term source of funding supporting both the ML and the WL high energy laser programs. The LEMEL capability was also enhanced with several lower power lasers operating at many different discrete wavelengths to address the threats posed by these lasers.

Dr. Gary Denman
Materials Laboratory Director
DARPA Director

As the SDI program grew Gen. Abe concluded that the ML laser effects modeling expertise and associated laboratory should be significantly enhanced to support the MDA program. He allocated nearly $40 M for LHMEL upgrades and transferred new manpower positions from MDA to AFRL for laser effects testing and analyses and strategic surveillance sensor development programs.

<u>Laser Hardening: Protecting US Systems Against Laser Threats.</u> The aerospace industry had many laser devices, some with very high power, to evaluate both weapon lethality and the vulnerability of US systems to these weapons. The LHMEL facility was unique, however, because of the highly refined

Gen Abe

John Spears

Gary Denman

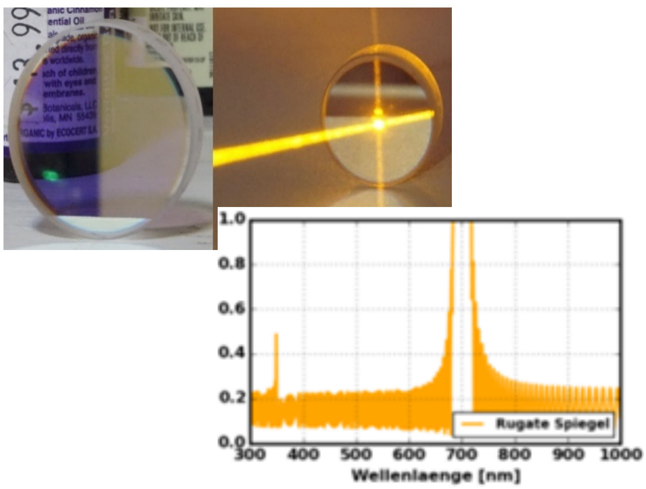
Missile Defense Agency upgrades at the LHMEL Laboratory Complex

diagnostics capability for measuring laser effects and sophisticated capability to analyze testing results. ML's established system support/ManTech/WCO presence was very effective in developing the partnerships with the AF system program offices.

In-house innovations were an important element of the program. The most significant of these efforts was the work of Conrad Phillipi developing rugate optical filters. This class of filters was used widely in astronomy to increase the precision of space observations by filtering out unwanted optical noise. Conrad believed this technology could be tailored to protect AF optical systems by precisely reflecting laser threat frequencies without diminishing the optical signal. For example, it these filters were applied to optical devices protecting the human eye (fighter pilot helmets) or commercial pilot glasses, it is critical that most of the light be transmitted through while reflecting only the damaging laser threat energy.

Conrad Phillippi

The challenge was the complexity of rugates. These filters are created by depositing 100s of layers a few atoms thick each with a slightly different composition. By carefully controlling the deposition process it was possible to fabricate filters which transmit all the light except for the extremely narrow frequency of a threat laser. With even more precise control of the deposition process the filter layers can be designed to reject multiple threat lasers each operating at a different frequency. While the analytical analysis which define the exact physical construct of the filters are complex, they are well developed. Conrad determined that multiple laser-reject features could be introduced and that available electronics industry semi-conductor manufacturing processes were sufficient to produce practical and reliable filters at low cost. These filters were designed to protect the most critical SDI and the DoD systems from threat lasers.



Rugate Filters

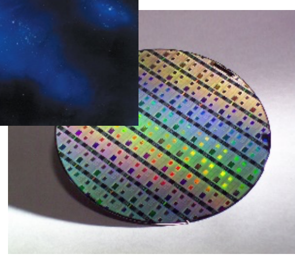
Air Force Maui Optical Site
AFRL Space/Directed Energy Directorates

The civilian astronomy community worldwide benefited as well when Conrad's improved rugate filters became available. The AFRL and AF facilities in Maui and the Starfire optical range in New Mexico used improved versions of these filters for space object identification and tracking for both AF Space Command and SDI customers.

Strategic Surveillance. The Defense Support System satellites, launched to geosynchronous orbit over a period of more than two decade, were the primary early warning systems for Gen. Schriever's ICBM program and later for MDA when the network became an element of Gen. Abe's SDI program. An array of ML satellite laser hardening techniques were applied to these satellites including rugate filters. Perhaps even more important was the earlier original ML in–house work including major programming partnerships with DARPA and later with SDI/MDA on a new class of very complex infra-red detector materials – mercury/cadmium/telluride (MCT). This IR semi-conductor family eventually revolutionized the capabilities of DSP and other IR focal plane array systems in space, in the air and on the ground.

This semiconductor composition family was discovered in Europe in 1959. ML immediately began evaluating and improving these materials for potential applications for both group and space applications, especially for DSP. Under the direction of Dr. Bill Fredericks and Dr. Gail Brown ML began programs in-house and large parallel efforts with the aerospace industry and the Air Force systems program offices, MDA and DARPA. This work was the basis for new families of IR focal plane arrays

DSP



IR Focal Plane Array

Dr. Bill Fredericks

Dr. Gail Brown

which revolutionized the arena; the arrays remain in widespread use in the military and commercial sectors worldwide.

After serving in ML and DoD headquarters in Washington Dr. Bill Fredericks became Chief Scientist of MDA. Dr. Brown received the AF Basic Research Award in recognition of her work.