

# GENESIS of INFRARED DECOY FLARES

The early years from 1950 into the 1970s



# Report Documentation Page

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# **GENESIS of INFRARED DECOY FLARES**

**The early years from 1950 into the 1970s**

**1<sup>st</sup> Edition**

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January 26, 2009

Cover image: Lockheed C-130 Hercules aircraft jettisoning decoy flares.

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## PREFACE

The idea to preserve information about the early development of target, augmentation and mainly infrared flares came about 15 years ago. I thought that collection of the information is needed because early records are sparse, scattered, and most are inaccessible to all but those in government. Most of the records were classified and even though the classification later was removed, the documents are not in the unlimited distribution category. As a government employee I could still access many of the records and hopefully extract pertinent information. There did not seem to be any urgency to complete the task. However as "retirement" appeared on the horizon, it became increasingly more urgent for me to compile the notes I had collected throughout my years of service. And now, I have reached the time that the task must be completed or it never will come to fruition.

My objective is to compile information relevant to the development of flares, mainly infrared decoy flares, during the 1950s through most of the 1970s. I wanted to make a conscious effort to preserve a small part of our national history. In later years, decoy flare data have been archived better and are easier to locate. However, most remain inaccessible to the public due to sensitivity limitations. And from a practical standpoint, the task to compile data that includes all developments into the 2000 era would be more than my limited time available would allow.

I'm certain I did not locate and capture all information relevant to decoy flares in the early years. Some of the information presented appears incomplete and does not flow continuously. Nevertheless, I tried to provide a synopsis of an event in an effort to give the reader a sense of the magnitude of the effort, the wide range of technology that was brought to bear, the thoroughness with which the researchers explored the problem, the urgency of the effort to provide a solution to a critical threat, the lack of sophisticated technology that would be needed to complete the development or flare evaluation effectively, and the huge number of flare developmental efforts ongoing simultaneously. With respect to data details about each flare, I provided an abbreviated description of the device when available and the application for which the item was designed. I recorded the item's existence even though information about it was meager.

Flare Terminology: The "jargon" used by flare developers and report writers especially in the early years tended to use the flare descriptive terms "target" flare and "augmentation" flare interchangeably. Similarly, during description of development, testing, or other flare event, the "Mod" of a flare was not always indicated, leading to some ambiguity. Exact terminology doesn't take hold until the device is officially assigned nomenclature usually when it transfers to production and service use.

Munition and Equipment Nomenclature: My objective includes the desire to identify equipment, aircraft, drones, dispensers, and related hardware by their assigned nomenclature. To do so helps to show how and what additional devices are required to be operative during deployment or testing of a flare.

Units of Measure: Due to the age of the material, most units of measure are presented in English units. Occasionally, the units are also provided in Systems International (SI) units.

A Note on Names: Included in my objective to compile data is my desire to record names of the researchers and the organizations with which they are associated. I believe it important to give credit to the individuals involved in the work. As one goes through the years of developmental effort, it becomes clear that certain individuals and organizations were heavily and continuously involved more so than others.

Upon first use of a name in the narrative, I provided the full name with title when known and employer identification complete with location. Upon further occurrence in the text, the individual is identified by "Sir" name only and title when known. The default title is "Mr."

Dates: Except where stated exactly, the dates given correspond to the date of the document such as a technical report from which the information was extracted. In reality, the actual dates during which the work took place is most likely a year or even two or three earlier than the report date. Similarly, the actual date of an invention cited in a patent is a year or more earlier that the filing-date of the patent application.

## **Acknowledgements:**

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## ACRONYMS and ABBREVIATIONS

3M	Minnesota Mining and Manufacturing
ACE	Advanced Cost Effective project
ADTC	Air Development Test Center, Eglin Air Force Base, Florida
AEDC	Arnold Engineering Development Center, Arnold Air Force Station, Tennessee
Aerojet-General	Aerojet-General Corp., Azusa, California.
AFAL	Air Force Avionics Laboratory at WPAFB
AFATL	Air Force Armament Test Laboratory, Eglin Air Force Base Florida
AFB	Air Force Base
AFCRL	Air Force Cambridge Research Laboratory, Laurence G. Hanscom Field, Bedford, Massachusetts
AFIT	Air Force Institute of Technology, WPAFB
AFSC	Air Force Systems Command
AGC	Aerojet-General Corporation
AIDES	Airborne Infrared Decoy Evaluation System
aka	also known as
AMC	U. S. Army Missile Command, Redstone Arsenal, Alabama
APGC	Air Proving Ground Center, Eglin Air Force Base, Florida
ARC	Atlantic Research Corporation, Saugus, California
ARC-Virginia	Atlantic Research Corporation, a division of Susquehanna Corporation, Alexandria, Virginia
ARD	Armament Research Department (UK)
ARF	Armour Research Foundation of IIT, Chicago, Illinois

ARPA	Advanced Research Projects Agency
ASD	Aeronautical Systems Division at WPAFB
ASP	Atmospheric Sounding Projectile
ASW	Anti-Submarine Warfare
ATIMS	Airborne Turret Infrared Measurement System
BATS	Ballistic Aerial Target System
BOF	Balls of Fire
BuAir	Navy Bureau of Aeronautics, Navy Headquarters, Washington, DC
BuOrd	Navy Bureau of Ordnance, Navy Headquarters, Washington DC
BuWeps	Bureau of Naval Weapons, Washington, DC
C2F4	tetrafluoro monomer
C3F6	perfluoropropene also known as hexafluoropropylene
CalTech	California Institute of Technology
CDC	Cooper Development Corporation, Monrovia, California
CTFE	chlorotrifluoroethylene, C <sub>2</sub> F <sub>3</sub> Cl
CTFE wax	Kel-F® #40
CTPB	carboxy-terminated polybutadiene
DEAC	diethylaluminum chloride
DEAH	diethylaluminum hydride
DEM	diethylmagnesium
DERA	Defence Evaluation Research Agency (UK)
DIBAH	diisobutylaluminum hydride

DRA	Defence Research Agency (UK)
DSTL	Defence Science and Technology Laboratory (UK)
DTI	DynaTech Inc., Tempe, Arizona
DuPont	E. I. du Pont de Nemours, Inc.
ECF	electrofluorination process
ECOM	Electronics Command, Fort Monmouth, New Jersey
EED	Electro-Explosive Device
EMCON	Emissions Control
EOD	Experimental Operations Department or Explosive Ordnance Disposal
ESD	electrostatic discharge
EX	experimental as in EX 46 Mod 0 flare
FA	Frankfort Arsenal
FAC	Forward Air Controller aircraft
FFAR	Forward Firing Aircraft Rocket flare
FFAR	Folding-Fin Aircraft Rocket
Flare Northern Division of ARC	Flare-Northern Division, Atlantic Research Corporation, Saugus, California
FM	frequency modulation
FOI	Federal Ordnance Incorporated, Mechanicsville, Maryland
FS-1265™ fluid	methyltrifluoropropylsiloxane
GD	General Dynamics Corp, San Diego, California
g/cc	grams per cubic centimeter
gran	granulation

HARP	High Altitude Research Program
HASC	High Altitude Simulation Chamber
HERO	Hazards of Electromagnetic Radiation to Ordnance
HISIP	High Speed Instrumentation Pod
HPAG	High Performance Air To Ground Rocket.
HVAR	High Velocity Aircraft Rocket
IIT	Illinois Institute of Technology, Chicago, Illinois
IITRI	Illinois Institute of Technology Research Institute
IPA	Isopropenylacetylene
IR	infrared
IRAD	Internal Research and Development Program
IRCM	Infrared Countermeasure
IRIS	Infrared Information Symposia
JHU	Johns Hopkins University
K	Kelvin temperature
Kellogg	M. W. Kellogg Company
KIAS	knots indicated air speed
MEK	methyl ethyl ketone
Mfg.	Manufacturer
MIT	Lincoln Laboratory, Massachusetts Institute of Technology
Mk Mod	Pronounced Mark and Mod as in Mk 46 Mod 1 decoy flare
MSL	mean sea level
MTV	Magnesium/Teflon®/Viton® A

NAD Crane	Naval Ammunition Depot, Crane, Indiana
NAVAIR	Naval Air Headquarters, Washington, DC
NBS	National Bureau of Standards
NMC	Naval Missile Center, Point Mugu, California
NOL White Oak	Naval Ordnance Laboratory, White Oak, Silver Springs, Maryland
NOLC	Naval Ordnance Laboratory, Corona, California
NOS Indian Head	Naval Ordnance Station, Indian Head, Maryland
NOTS	Naval Ordnance Test Station, Inyokern, China Lake, California
NPF Indian Head	Naval Powder Factory, Indian Head, Maryland
NPG Dahlgren	Naval Proving Ground, Dahlgren, Virginia
NPP Indian Head	Navy Propellant Plant, Indian Head, Maryland
NRL	Naval Research Laboratory, Washington, DC
NWC China Lake	Naval Weapons Center, China Lake, California
NWSC Crane	Naval Weapons Support Center, Crane, Indiana
ONR	Office of Naval Research, Washington, DC
ORI	Ordnance Research Incorporated, Fort Walton Beach, Florida
OSDR	Office of Scientific Research and Development
PA	Picatinny Arsenal, Dover New Jersey
PBX	plastic bonded explosive
PENVAL	Penetration Evaluation Program
PETN	pentaerythritol tetranitrate
PFHM	polyfluoroheptylmethacrylate

PL	Pilot Lot
PMTC Point Mugu	Pacific Missile Test Center, Point Mugu, California
PMVT	polymethylvinyltetrazole
PPE	Prototype Production for Evaluation
PTFE	polytetrafluoroethylene
QRC	Quick Response Capability
Rad	A rad is a unit of radiation quantity of absorbed dose. One rad is equal to energy absorption of 0.01 J/kg of any material
RAE Farnborough	Royal Aircraft Establishment, Farnborough, Hants, England
RARDE Fort Halstead	Royal Armament Research and Development Establishment, Sevenoaks, Kent, UK
RARDE Langhurst	Royal Armament Research and Development Establishment, Langhurst, Horsham, West Sussex, UK
RBOC	Rapid Blooming Offboard Chaff
RF	radio frequency
RMC200	Reade Metals Corporation granulation grade 200 magnesium powder
RTD Eglin	Research and Technology Division, Eglin Air Force Base, Florida.
S&A	safe and arming device
SCAR	2.25-inch Sub-Caliber Aircraft Rocket
SI	Systems International
SOID	Ships Ordnance Infrared Decoy
SR	Superintendent for Research
SRI	Stanford Research Institute, Menlo Park, California
TEA	triethylaluminum

Thermoplastic 125	styrene-butadiene copolymer
TME	trimethylethylene
TNPA	tri-n-propylaluminum
UK	United Kingdom
UMC	Universal Match Corporation, Saint Louis, Missouri
USA	United States of America
USAF	United States Air Force
USF of ARC	U. S. Flare Division of Atlantic Research Corporation
USFC	US Flare Corporation, Pacoima, California
USN	United States Navy
UTC	United Technology Center, Sunnyvale, California
µm	micrometer
VF2	vinylidene fluoride
Vistanex®	a polypropylene polymer
VX-4 Point Mugu	Air Test and Evaluation Squadron Four, Point Mugu, California
W/sr	watts per steradian
WADC	Wright Air Development Center, WPAFB
WMU	Weather Modification Units
WPAFB	Wright Patterson Air Force Base, Dayton, Ohio
WW II	World War II



## INTRODUCTION

The evolution of decoy flares did not follow a direct or pre-planned path. Instead, the development was influenced by many factors and requirements existing at the time. One of the most important of these is that the Naval Ordnance Test Station (NOTS), Inyokern China Lake, California had an assigned mission to develop rockets and missiles. This mission became the basis for the requirement that drove flare developments. Fortunately there were a number of ongoing projects at China Lake that supplied expertise and the technological foundation. These were important for the Sidewinder missile and infrared decoy flare developments. Discussions of these topics follow.

### ORIGIN of the SIDEWINDER MISSILE SEEKER

The saga of the development of the Sidewinder missile revolves about one brilliant scientist at NOTS with a vision. Dr. William Burdette McLean, father of the Sidewinder, began to conceive of the Sidewinder missile in the 1940s. Dr. McLean proposed the air-to-air target seeker to the Washington DC hierarchy in November 1947 and demonstrated it in February 1948. To fully understand details of the improbable development of the Sidewinder heat-seeking missile and the genius of Dr. McLean, one needs to read the book, *Sidewinder, Creative Missile Development at China Lake*.<sup>1</sup>

The ingenious management talent of Dr. McLean, in the environment of NOTS China Lake during the 1940s and 1950s, is one of his attributes that made the Sidewinder missile a success. He organized teams of individuals whom he selected. He either personally interviewed and hired prominent scientists for his teams or had them assigned from other segments of NOTS China Lake but only after a personal interview and selection process. Not only did the individuals need to have outstanding technical talent and reputations but they also had to have a driven work ethic and a can-do attitude. Work after hours, at the swimming pool, during an evening dinner at his home and in the middle of the night was the norm. To cope with the urgency, he often assigned the same goal to multiple competing teams to increase the probability of an early solution to the problem at hand.

The team of Dr. Lucien M. Biberman of the Office of Associate Director for Research and Development of NOTS and Mr. Edwin G. Swann and Mr. John J. Miyata of the Research Department Optics Branch of NOTS was created by Dr. McLean to solve the detector and tracking difficulties when operating in a sky background. Mr. Swann and Mr. Miyata were on assignment from the Optics Branch through the cooperation of the Branch Head Mr. Walter Wallin. The organization of

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<sup>1</sup> Westrum, Ron Sidewinder. Creative Missile Development at China Lake. Naval Institute Press, 291 Wood Road, Annapolis, Maryland, 1999: ISBN 1-55750-951-4.

such a “Consultants Group” under the guidance of Mr. R. S. Estey is one example of Dr. McLean’s management skills. Their task assigned prior to 1951 was to design a photocell and electronic components for a heat homing system. The feasibility study was called Fox Sugar 567 and had started earlier as local project 612.

The report of the Consultants Group describes the design of the photocell and electronic details of an infrared homing device for a rocket. They discuss variables associated with the amplifier bandwidth and time constants of lead sulfide cells, a limiting design factor. They show how a multi-slit scanner and a special slit pattern can be used to strongly suppress the sky background. They describe an amplifier that uses the signal to control currents in four precessing coils or control circuits that represent the direction and radial distance of the target image from a reference on the missile axis.

The entire program was under the direction of Dr. McLean. Reviewers of the work of the Consultants Group were Dr. McLean, Mr. F. T. Rogers, and Mr. Estey. The Associate director for Research and Development was Mr. F. W. Brown. Mr. L. T. E. Thompson was the Technical Director of NOTS at this time.<sup>2</sup>

Dr. Marshall D. Earle of the Aerospace Corporation in Los Angeles California, in 1978 while describing the principles involved in infrared tracking devices wrote, “The phenomenal success of this type of missile is from two achievements: the development of short-time constant high sensitivity photoconductive detectors and development of means by which a small target which occupies only a small part of the field of view can be distinguished from its background.” This was the seminal achievement of Dr. Biberman’s team. In *Spectral Reflections*<sup>3</sup> it states Dr. Biberman invented the missile guidance concept used in several generations of Sidewinder missiles: conceived missile warning technology now used by Special Forces and Marine aircraft; and played the key role in designs of AIM-9 Sidewinder missiles.

The first flight tests of Sidewinder (EX-0) missiles took place starting 14 May 1952. The missiles were fired at an F6F-5K drone aircraft from an A4-D aircraft. The Sidewinder missile was introduced into the U. S. Navy Fleet for the first time in 1956.

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<sup>2</sup> The title of the above researchers and others in this document most likely is “Dr.” instead of “Mr.” which was assigned by default when unknown.

<sup>3</sup> *Spectral Reflections*. Newsletter published by Infrared Information and Analysis Center (IRIA), Michigan University, Ann Arbor, Michigan. January 2000.

## ENABLING TECHNOLOGIES

To develop a heat-seeking missile, a number of enabling technologies needed to be developed or improved upon. For example, seeker technology and algorithms were needed to distinguish the target from the background. A photoconductive cell detector was needed. Computational methods and hardware were inadequate. Radiometric and spectral instruments were either non-existent or in their embryonic state. Measurement capability was needed in the infrared, ultraviolet and in the visible for utilization on the ground and in the air. No airborne radiometric and spectral instrumentation existed. Equipment to test and evaluate flares to simulate functioning at altitude also did not exist and although research in fluorocarbon chemistry was ongoing at NOTS, it needed to be adapted to the current needs. To complement their growing ability to make measurements in the infrared, ultraviolet and visible spectral regions, in 1954 NOTS assembled an electronic countermeasures test facility consisting of off-range facilities and equipment, range instrumentation, and a mobile caravan containing jammers, intercept equipment and transmitter-receivers. All these technological areas needed to be advanced sufficiently to enable their adoption into a missile seeker design. As technologies advanced there was need to test the seeker concepts first against drones and finally in live-fires. This required development of augmentation flares, target flares and ultimately infrared decoy flares in order to be able to record the event with some accuracy.

### **Lead Sulfide and Lead Selenide Photoconductive Cell Detectors**

Photo-conductor technology was critical to the development of the Sidewinder missile by NOTS. The lead sulfide (PbS) photoconductive cell was chosen to be the detector of visible energy radiated from rockets and missiles and later of near-infrared radiation from the targets, aircraft, missiles and rockets. Without this device, the Sidewinder missile would not be able to engage its target. The lead sulfide detector also was used to measure the radiative output in the visible and near-infrared region of tracking flares, augmentation flares, and infrared decoy flares. In the early 1940s, the detector had not been sufficiently developed to allow direct application into a device. Additional development was needed, some of which took place at NOTS.

One can review the background of the evolution of the lead sulfide photoconductive cell. On 30 September 1901, Mr. Jagadis C. Bose of Calcutta India filed for a patent for a Detector of Electrical Disturbances later to become U. S. Patent 755,840 in 1904. Mr. Bose had discovered the photosensitive property of lead sulfide (galena). In 1917, Mr. T. W. Case reported the change of resistance of certain substances to light. Later, lead sulfide detectors were developed in Germany by Mr. Gudden in the 1930s and were used in some systems in World War II (WW II). In 1944, Mr. R. J. Cashman developed the first practical lead sulfide detector in the U. S. In 1951, Dr. Biberman of the Office of Associate Director for Research and Development and

Mr. Swann and Mr. Miyata of the Research Department Optics Branch of NOTS, reported on the Design of Photocell and Electronic Components for a Heat Homing System. The technology developed and reported in that study provided one of the critical technologies needed to build the Sidewinder missile.

In 1957, the Navy Bureau of Aeronautics (BuAir) in Navy Headquarters Washington, asked China Lake to evaluate lead selenide nitrogen-cooled photoconductive cells. Mr. Victor A. Ereaux and Mr. Eugene K. Lawson of the Aviation Ordnance Department at NOTS conducted the study of cells made by Santa Barbara Research Center, Goleta California. They made measurements of spectral response and blackbody radiation. Detector research at China Lake, including lead sulfide studies, continued into the late 1960s.

### **Thermodynamic Computations and the Analog Computer**

About the same time, 1950, Dr. William S. McEwan of the NOTS Research Department reported on a system for the computation of gaseous products of combustion to determine their equilibrium composition and thermodynamic properties of the combustion gases.

In 1951, Dr. McEwan and Dr. Sol Skolnik developed an analog computer that electrically simulated the conditions of temperature, pressure and composition of rocket and missile combustion products. With these improved computational capabilities, they were able to make better and quicker estimates of rocket and missile performance.

### **Radiometric and Spectral Measurement Instrumentation**

The ability to perform radiometric and spectral measurements also needed to be developed to measure the radiative and spectral output of rocket and missile plumes, exhaust plumes of aircraft and the output of flares of all types. During development of tracking flares, China Lake employees needed the ability to measure characteristics of energy radiated from the burning devices in the visible region as well as in the infrared region of the spectrum. Fortunately, the Technology Department had an ongoing effort to continually improve the equipment and techniques while other developments were in progress. In addition, other laboratories also were building improved measurement instrumentation. Collectively, these efforts provided improved means to make measurements thereby enabling flare developers to better assess their technological advances.

Even as late as 1976, Picatinny Arsenal provided a list of instrumentation needed for pyrotechnic research and technology. These are: (1) stable photocells and stable amplifiers, (2) high speed spectrograph, (3) high sensitivity infrared photocells, (4) rugged, portable and simple to operate color meters for flares, (5) a light integrator for flares, and (6) rapid computers and integrators for flash evaluation. This deficiency list is an example of some of the technological voids at

that time. It is surprising to learn that high quality capable instruments that we take for granted today were unavailable to the researchers of that era.

The Experimental Operations Department (EOD) of NOTS developed and made measurements of the Forward Firing Aircraft Rocket (FFAR) flare, reported in 1946. They also experimented with measurement of the illuminating characteristics of 3-inch and 4-inch projectiles and aircraft flares. Trajectory measurement of the Target Rocket Mk 3 was reported by the Science Department in July 1946. Between June 1956 and January 1957, Mr. David Gilbert and Mr. Frank B. St. George measured flare radiant output using a locally developed NOTS Model 34A radiometer. This radiometer used a lead sulfide detector capable in the 0.5 $\mu$ m to 3.0 $\mu$ m bandpass region.

About 1954, Dr. Earle, Johns Hopkins University (JHU) Carlyle Barton Laboratory (Radiation Laboratory) constructed a Rapid Scan Spectrometer that might have been the forerunner to the Perkin Elmer Model 108 spectrometer that became ubiquitous in pyrotechnics laboratories. His spectrometer could scan at 1 per second through the visible up to 1.2 $\mu$ m and from 1 $\mu$ m to 4 $\mu$ m in the infrared.

In mid-1956, under contract to the Wright Air Development Center (WADC), Wright Patterson Air Force Base, Dayton Ohio (WPAFB), the Eastman Kodak Company, Rochester New York, developed ground and airborne instruments for measuring the infrared radiative output of jet engines, rockets, and flares. They installed a Perkin Elmer Rapid Scan monochromator into an F-94 pylon tank. The monochromator was wrapped in a heating blanket. Its line of sight was through a sapphire window.

In 1955 -1956, the Navy Bureau of Ordnance (BuOrd) assigned a task to China Lake to develop a photometric system for measuring intensity and duration of pyrotechnic signals. Initially the instrument was intended to measure the output of the Mk 37 Mod 0 flash signal for the Sparrow III guided missile, the Mk 36 Mod 0 flash signal for the Sparrow II missile, and the Mk 1 Mod 0 flash signal and Mk 2 Mod 0 flash signal for the Sidewinder exercise head. The light intensities from these emitters ranged between 100,000 candela and 200,000,000 candela with durations of less than 5 milliseconds to several seconds. The flash signals were used during missile tests to indicate fuze action. The NOTS Model 751A flash signal indicates fuze actuation for the Sparrow I missile.

Efforts continued to improve measurement accuracy. During 1958, Mr. H. I. Sumnicht of the Aviation Ordnance Department of NOTS observed that when using radiation detectors, there is a need to quantitatively determine the degree that a source will affect a response in the radiation detector whose response curve shows spectral variation. To remedy that deficiency, he developed a method whereby the unknown radiative source is evaluated by comparing it with a source of known power distribution.

Under the auspices of the Metrology Department of the Bureau of Naval Weapons (BuWeaps) at Pomona California in 1958, eleven U. S. Navy calibration labs were established because of overload at the National Bureau of Standards (NBS). Their tasks included the calibration of a blackbody and an optical comparator system in support of decoy flare tests and other Navy programs. The primary blackbody followed the design developed about 1950 by an NBS standards group at the Naval Ordnance Laboratory, Corona California (NOLC).

During a 1960 Conference, Mr. Philip J. Smith of the Naval Ammunition Depot (NAD), Crane Indiana presented problems encountered in making luminous intensity and infrared measurements. The test tunnel configuration, positioning of the test unit, smoke obscuration, smoke exhaust, and measurement instrumentation were discussed. Mr. Armin T. Wiebke of NOTS described the instrumentation that had been developed at China Lake. That instrumentation included a vacuum phototube for measurement in the visible region and lead sulfide cells mounted behind interference filters for infrared measurement in the 2 $\mu$ m to 3 $\mu$ m bandpass region.

Efforts to improve measurement of the output of infrared decoys continued. About 1960, Mr. Jason Sarnow of the Navigation and Guidance Laboratory, Wright Air Development Center, WPAFB reported on a convenient method for correcting errors in spectral analyses of high energy sources resulting from attenuation due to atmospheric and filter factors in the region of 0.3 $\mu$ m to 6.3 $\mu$ m bandpass region in 0.2 $\mu$ m increments. In 1961, Mr. Ephraim Regelson, Mr. D. K. Burge, and Mr. M. Wayne Claunch of China Lake reported development of a color wheel radiometer using eight filters covering the range from 2 $\mu$ m to 6 $\mu$ m bandpass region. The radiometer was used to acquire spectral information about the Mk 28 Mod 0 target flare (NOTS Model 711A flare) and the NOTS Model 712A target augmentation flare.

Also about 1960, Mr. E. J. Cleary and Mr. J. R. Carter of China Lake developed an airborne color wheel spectral-radiometer to measure radiant energy in the 2 $\mu$ m to 5 $\mu$ m bandpass region. It is packaged in a 5-inch diameter tube by 92 inches long and can be mounted on any aircraft equipped to carry Sidewinder missiles. The instrument is designed to function at altitudes up to 50,000 feet and at speeds of Mach 1.6. The data are recorded on 16-mm film. They collected radiative data from the exhaust of the B52-H turbofan aircraft and compared measurements of ground-burning flares to airborne-burning flares.

A second type of NOTS airborne radiometer was developed about 1961. It was a fixed-band device utilizing a liquid nitrogen cooled lead selenide detector and an optical interference filter with a 2.5 $\mu$ m to 5.0 $\mu$ m bandpass. This equipment was mounted under the wing of an F-3D aircraft for measuring the radiative output of airborne flares.

In 1962, Baird Atomic, Incorporated, Cambridge Massachusetts reported the development of a turret mounted scanning spectrometer capable of making spectral measurements using cooled lead selenide detectors of 0.2 $\mu$ m resolution in the 1.5 $\mu$ m to 4.7 $\mu$ m bandpass region at altitudes above 65,000 feet.

Mr. Ralph Zirkind of the Advanced Research Projects Agency (ARPA), Lt Col Lavern A. Yarbrough USAF, Dr. Paul J. Cvrebo of AFSC and Mr. Lawrence W. Nichols of NOTS presented a paper entitled Techniques for Measurements of Infrared Radiation Characteristics of Airborne Targets at a NATO May 1963 meeting in Paris France of a group of experts on far infrared. The NATO community observed apparent discrepancies in the data. As a result, the group undertook the task to evaluate about 24 instruments in service use and some developmental items.

As part of infrared spectroscopy research at China Lake in the mid-1960s, the investigators continued to evaluate circular variable filters. The quest for improved instruments for measurement of infrared radiation from missiles, aircraft and flares was continuing with vigor. During 1964 and 1965 meetings of the Infrared Information Symposia (IRIS) many papers on detector materials and transmission glasses were presented. Also included were presentations about a high performance interferometer for airborne applications, an airborne infrared spectrometer system, an infrared band ratio technique to determine temperature, and a method to obtain the concentration ratio of carbon dioxide to water (CO<sub>2</sub>/H<sub>2</sub>O) in rocket exhaust plumes.

In May 1963, a Specialty Group of IRIS concluded that the physical standardization of radiation sources was one of the most important areas to cover on a continuing basis. As a result, a survey was made of radiation-source standardization. Five laboratories in the USA are listed as having formal radiation-source standardization programs: (1) National Bureau of Standards, Washington, D.C., (2) U. S. Air Force Calibration Group, Newark, Ohio, (3) The Eppley Laboratory, Inc., Newport, Rhode Island, (4) Bureau of Naval Weapons Representative, Pomona, California, and (5) Hughes Aircraft company, Tucson, Arizona. The National Physical Laboratory at Teddington, England was added to this review. Three types of radiation standards were considered: blackbody radiation source standards, detector standards, and incandescent source standards. Comments were made on the problems of temperature, cavity theory, polar angle, NBS traceability, and calibration procedures. They identified the need for a blackbody calibration service. The team noted that accuracies for radiation-source standardization measurements are 0.2% to 5% or even larger percentages depending on the type of measurement.

In May 1963, Mr. Regelson of China Lake filed for a patent for an infrared calibration lamp. His objective was to provide an infrared calibration source that was suitable for field use where environmental conditions make it difficult to use laboratory type standards. Another objective was to provide an infrared source

small enough to serve as an internal source for radiometric equipment that offered a combination of accuracy, small size, ruggedness, and low cost.

In a 1968 report, Mr. G. S. Amick of Airtronics, Inc in Washington DC conducted a deviation analysis of infrared measurements in an effort to develop a standard way of doing infrared countermeasure measurement and tests.

ALA-17 flares and ALA-34 flares were tested at Eglin Air Force Base about 1970 with an Air Force developed Airborne Infrared Decoy Evaluation System (AIDES), a 2-color radiometer operating in the 3.8 $\mu$ m to 4.9 $\mu$ m bandpass region with a lead selenide detector and in the 1.8 $\mu$ m to 2.7 $\mu$ m bandpass region with a lead sulfide detector. The AIDES pod is mounted in or on a MacDonnell Aircraft Instrumentation Pod, which is suspended from an F-4C aircraft. The AIDES pod carries an AIM-9B Sidewinder and an AIM-4E Falcon. Dr. David J. Edwards of the Air Development Test Center (ADTC) at Eglin Air Force Base managed this effort.

### **High Altitude Simulation Chamber**

A High Altitude Simulation Chamber (HASC) was built at NOTS in support of their High Altitude Research Program (HARP). To fill the need for evaluating performance of flares at high altitude, Dr. George S. Handler of China Lake took the lead to install a rapid scanning infrared spectrograph in the HARP high altitude chamber about 1963. A photo multiplier tube is used to record visible and near infrared energy, a lead sulfide cell is used for the 0.5 $\mu$ m to 3.0 $\mu$ m near infrared and a lead selenide cell is used for the 4.5 $\mu$ m to 6.0 $\mu$ m bandpass region. Later, during 1970, the HASC was modified to enable experiments at 0.8 Mach and 40,000 feet altitude. A choke flow diffuser flow system was added to make possible the determination of flare characteristics at altitude and various subsonic velocities.

### **How Teflon®, Viton®, and Kel-F® Came into Being**

In 1996, Mr. Davis Shryer<sup>4</sup>, a long-time 3M employee, related the story from personal recollection of how tetrafluoroethylene was discovered and also the background of the evolution of Kel-F® wax, Kel-F® elastomers, Viton® A and other fluorocarbon materials. He noted that its accuracy may be slightly tainted by time, but that the essentials are correct.

He said, as far as the USA is concerned, the story has to begin with E. I. Dupont, which invented and produced fluorocarbon refrigerant gases (Brand named "Freon") in the first decades of the 20th century. An E. I. Dupont researcher named Dr. Roy Plunkett was experimenting in the 1930s with a tetrafluoro monomer (C<sub>2</sub>F<sub>4</sub>), derived from by-products of the "Freon" process. One day in his laboratory Dr. Plunkett attached a small cylinder of this gas to an apparatus intending to

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<sup>4</sup> Personal communication with Mr. Davis M. Shryer, retired from the 3M Company, and later a consultant to the Mach I Corporation. 1996.

introduce the gas into a reaction vessel. When he opened the cylinder valve, no gas emerged. The incident became known as "Plunkett's Perplexity", because upon removing and weighing the C<sub>2</sub>F<sub>4</sub> cylinder, he found that its weight had not changed. Where then were the contents? To find out what had happened to the gas, he cut open the cylinder and found a white waxy solid. This, in 1938, was the first discovery of polytetrafluoroethylene (PTFE) that was later, branded "Teflon®". Subsequently, E. I. Dupont produced PTFE for seals, gaskets, etc for use in the chemical processes of the Manhattan Project, where highly corrosive intermediates such as sulfur hexafluoride were processed.

The M. W. Kellogg Company (Kellogg) produced chlorotrifluoroethylene (CTFE, C<sub>2</sub>F<sub>3</sub>Cl) plastics and lubricants for the Manhattan project and at the end of WW II elected to manufacture them commercially under the brand name "Kel-F®". Dr. Miller at Cornell University had developed CTFE under a U. S. government contract. Kellogg also produced fluoroelastomers that were copolymers of CTFE and vinylidene fluoride (VF<sub>2</sub>), an available monomer. It turned out that these elastomers had a lower degree of oil resistance than 3M's fluoroacrylates and were extremely difficult to process into finished rubber goods.

During their research on the CTFE/VF<sub>2</sub> polymer elastomers, Kellogg obtained very small experimental quantities of perfluoropropene (C<sub>3</sub>F<sub>6</sub>, also known as hexafluoropropylene) and copolymerized it with VF<sub>2</sub> to create an elastomer they believed to be superior for turbine engine O-rings. Unfortunately, the C<sub>3</sub>F<sub>6</sub> was prohibitively expensive for Kellogg to produce or purchase. However, E. I. Dupont produced the C<sub>3</sub>F<sub>6</sub> and made it commercially available. Concurrently in the 50s, the Air Force had been sponsoring the development of chemically resistant elastomers for aircraft engine O-rings, gaskets and seals. In 1956, E. I. Dupont approached Air Force scientists at WPAFB with the C<sub>3</sub>F<sub>6</sub>/VF<sub>2</sub> copolymer they brand named "Viton® A". The E. I. Dupont Company was the first to market Viton® A. Subsequently, the Air Force dropped 3M's fluoroacrylates and Kellogg's CTFE copolymers from consideration, the E. I. Dupont C<sub>3</sub>F<sub>6</sub>/VF<sub>2</sub> copolymer being a superior elastomer. In 1957, Kellogg sold its process and its small factory to the 3M Company.

The 3M Company embarked into fluorochemicals in 1947-48 when they purchased the electrofluorination process (ECF) that Dr. Joe Simmons of Penn State University had developed. The ECF process was a more efficient way to produce long chain fluorocarbon molecules that are used in surfactants, textiles, paper, leather, etc. However, it was E. I. Dupont that produced the fluoropolymers in subsequent years at a lower cost. Allied Signal in the US, ICI in England, ATOChem in France, Hoechst in Germany, Asani and Daikin in Japan, and Montedison in Italy emulated the E. I. Dupont process.

In 1959, 3M took over Kellogg's research and development of fluoroelastomers and introduced the "Fluorel" brand of fluoroelastomers, a material essentially identical to Viton® A. Until the 3M Company obtained access to low-cost monomers, 3M was at

a competitive disadvantage. This changed in the 60s and in the 70s as worldwide production of the monomers grew as C<sub>3</sub>F<sub>6</sub>, VF<sub>2</sub>, and others became more available.

## Exploration of Fluorocarbon Compounds

It is fortuitous that a research group was in place at China Lake to study and develop fluorocarbon polymers. These researchers became the leaders in developing the polymer technology that later would be needed for decoy flare development.

Starting in 1950, Mr. Frank G. Crescenzo, Mr. Elmo C. Julian, and Mr. Robert C. Meyers at China Lake conducted theoretical and experimental studies of metals mixed with fluorocarbon compounds and possibly with addition of perchlorates. Their formulation studies of composition PL 6010 to PL 6085 formulae (PL stands for Pilot Lot) included magnesium, aluminum, boron, thorium, zirconium, molybdenum, and titanium as the fuels; Teflon®, lithium perchlorate, potassium perchlorate, sodium fluoride, potassium chromate as the oxidizers; and Kel®-F oil #10 as a fluorine carrier and binder. This may be the earliest record of experiments with mixtures of magnesium, Teflon®, and the fluorochlorocarbon, Kel-F® produced by 3M formerly the Kellogg company. The NOTS team also calculated the heats of reaction for the fuel-oxidizer combinations and estimated the reaction temperature. A list of composition PL numbers is included in the APPENDIX.

On 13 June 1957, Mr. Crescenzo, Mr. Julian, and Mr. Meyers of NOTS filed for a patent for an igniter composition.<sup>5</sup> This is an igniter for gas producing charges such as propellants, fuels, and explosives. The igniter is composed of a 30% to 85% mixture of Teflon® with Kel-F® wax; 15-70% fuels like magnesium, aluminum, boron, thorium, zirconium, and titanium; about 1-10% potassium dichromate, manganese dioxide, ammonium nitrate or ammonium perchlorate; and 1-10% lead fluoride or sodium fluoride. This work in part provided the technical foundation for the development of infrared tracking and decoy flares and may be the earliest known work related to the development of infrared decoy flares. Binary mixtures of magnesium and Teflon® to which Kel-F® wax is added as a third ingredient were first developed at China Lake in 1955. About 1959, Viton® A started to be added to the magnesium-Teflon® binary formulations in place of the Kel-F® wax.

Researchers at China Lake by 1954 were also combining fluorocarbon and chlorofluorocarbon materials with explosives. Energetic material scientists at Los Alamos National Laboratory (Panowski et al), at Lawrence Livermore (James, Scribner, et al) and at China Lake (Dr. Harold Gryting et al) were making PBX with Kel-F® elastomers and with Viton® A as binders. Knowledge of those materials provided the technological basis for their use in flares. NOTS researchers examined

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<sup>5</sup> Crescenzo, Frank G., Elmo C. Julian, and Robert C. Meyers. Igniter Composition. U. S. Patent 3,753,811. The patent was filed on 13 June 1957, was allowed but was held under a Secrecy Order until 21 August 1973, when it issued.

explosive mixtures of magnesium powder and liquid fluorocarbon derivatives in 1954. They found that a slurry of magnesium with benzotrifluoride and fluorocarbon derivatives could be detonated by explosive shock from a #8 blasting cap. Burning rate studies of liquid fluoronitrocarbon systems continued in 1956, as did studies of magnesium-fluorocarbon-oxidizer pastes, the latter in a search for non-explosive monopropellant liquids for underwater propulsion. China Lake researchers continued to conduct fluorinated-polymer research into the mid 1960s.

On February 17, 1956, Mr. Edgar A. Cadwallader<sup>6</sup> of the Naval Ordnance Laboratory (NOL), White Oak Silver Springs Maryland filed for a flare composition patent. The object of this invention was to make an illuminating flare by combining trifluorochloroethylene with one or more alkaline earth metals. This work is most likely connected to the ongoing target flare development tasks at China Lake in the middle 1950s.

About 1959-1962, CTFE wax (Kel-F® #40), was the binder used in infrared decoy flares being produced at NAD Crane. With the ready availability of Viton® A, it was logical that someone at China Lake or NAD Crane would try Viton® A as a binder for the binary mixture of magnesium and Teflon®. China Lake did this and Viton® A quickly became a replacement for Kel-F® wax. Because of its superior performance, Viton® A soon became the material of choice and the term MTV which stands for Magnesium/Teflon®/Viton® A became a generic acronym.

There was almost continuous work at China Lake into the mid 1960s to develop improved binders for pyrotechnics. In one such an effort, preliminary evaluation was given to a cellulose acetate butyrate rubber, a styrene-butadiene copolymer (Thermoplastic 125), and a polypropylene polymer (Vistanex®). The research team sought suitable solvents such as hexane to dissolve the rubbers to create a fluid in which solids could be dispersed. Their objective was that during extraction of the solvent and subsequent precipitation of the binder material onto the solids' surfaces, a homogeneous mixture of discrete coated particles would result. The styrene-butadiene copolymer did not coat Teflon®. In a similar way a few years later, Krayton 101 and Nordel™ 1145 binders were explored. Krayton 101 had no adhesion to a magnesium-Teflon® grain and neither did Nordel™ 1145. Estane®, a polyurethane rubber did not coat the solids when precipitated with hexane. The team determined that isopropanol, as the solvent medium is better than hexane.

During 1969 and 1970, Mr. Edward A. Allen of NOTS investigated using Vitel® polyester resin types PE-200/PE-222/PE-207, Sylgard® 182 and Sylgard® 184 dimethylsiloxane as a binder to replace the expensive Viton® A, a fluoroelastomer by E. I. Dupont. When formulated into a flare, the composition with the Vitel® polyester radiated better in the 3µm to 5µm bandpass region than in the 2µm to

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<sup>6</sup> Cadwallader, Edgar A. Flare Composition. U. S. Patent 3,152,935. October 13, 1964. The patent was filed February 17, 1956.

3µm bandpass region. However, Viton® A performs better than Vitel® especially at simulated high altitude. The work continued in 1971 to cast flares with Sylgard® 182, potassium hexafluorophosphate, potassium perchlorate, magnesium and Teflon®. The radiant intensity was acceptable in the 3µm to 5µm bandpass region but the flare had a long burning time. Mr. Allen also tested a pressed grain with a Dow-Corning Corporation Midland Michigan product identified as FS-1265™ fluid (methyltrifluoropropylsiloxane) containing 30% fluorine, and reported that the infrared radiant intensity emitted by the flare in the 2µm to 3µm bandpass region was greater than the 3µm to 5µm bandpass region.

As a part of pyrotechnic supporting research, in June 1969 Dr. Handler, Mr. Armin Webke, Mr. F. Martinez, and Mr. D. Sbrocca of NOTS investigated the use of Vitel® and Hycar binders as a substitute for Viton® A. Vitel®, Sylgard® and Hycar™ were compared to composition PL 6328 the standard mix in the Mk 46 Mod 0 decoy flare. The team reported that a satisfactory molding powder could be made with Vitel®, which is suitable for extruding devices up to 1-inch in diameter. The best Vitel® formula is 75.2% magnesium, 13.8% Teflon®, and 11% Vitel®. This composition burns much too slowly and degrades significantly at altitude. At 35,000 feet altitude, the composition with Viton® A loses 20%, the composition with Sylgard® loses 50% and the composition with Vitel® loses 60% of its infrared radiant intensity. Degradation at high altitude is ascribed to a cooling effect and reduced pressure, which slows the reaction. About 63% magnesium is needed in the composition to sustain burning when Vitel® is used.

During 1970, China Lake investigators compared Fluon® G-3 and Halon G-10 to Teflon® #8 and Teflon® #7. Fluon® and Halon are brand names of a material similar to Teflon®. The investigators reported radiative efficiencies for Fluon® and Halon to be similar to Teflon®.

In 1971, the Teflon® supplier reported that production of Teflon® #7 and Teflon® #1 was being discontinued. This caused appreciable difficulty to infrared decoy developers. As a work-around, Teflon® #7C was considered as a substitute for Teflon® #7 in the EX 49 Mod 0 decoy flare. The formulations in the Mk 42 Mod 0 decoy flare, Mk 43 Mod 0 decoy flare, and the Mk 46 Mod 0 decoy flare were also affected because of the Teflon® #1 non-availability.

The Naval Weapons Center China Lake (NWC) reported a castable fluorocarbon binder in 1973. It consists of Viton® A, Viton® LM, and hydroxypropylmethacrylate cured with benzoyl peroxide and methylene diacrylate as a crosslinker.

During 1978-80, NAD Crane and decoy flare contractors incorporated Fluorel® FC-2175, a 3M product into their specifications as a Viton® A equivalent.

## HAZARDS of ELECTROMAGNETIC RADIATION to ORDNANCE

HERO is the acronym for Hazards of Electromagnetic Radiation to Ordnance. During the late 1950s, it was known that the Mk 6 Mod 13 torpedo exploder mechanism could be set off by radio frequency (RF) energy. Also, there were aircraft carrier incidents during which Electro-Explosive Devices (EEDs) contained in ordnance were initiated while the ordnance was being loaded onto the aircraft. As a result, Emissions Control (EMCON) measures were recommended but were unpopular with the U. S. Navy because EMCON could mean loss of vital communication with planes during operations. By 1952, EMCON had been de-emphasized; but by 1956, EMCON had been changed from a recommended action to a requirement as a result of growing awareness of the need for a HERO program. Even today, Navy decoy flares and other energetic materials must meet the requirements of the HERO program.

A group of engineers, scientists, and technicians was assembled at the Naval Proving Ground (NPG), Dahlgren, Virginia to test instrumentation and techniques aboard the USS CONSTELLATION using weapon "A". A test was conducted in March 1958 aboard the USS ROOSEVELT of 2.75-inch rockets for which there was a large "unexplained" accident/incident file. The following year, HERO was formally organized at NPG Dahlgren.

In the past, accidents with ordnance were poorly documented, especially if the cause is not easily identifiable; i.e., improper methods, physical abuse, poor techniques. Prior to the 1960s, the reporting of accidents concerning ordnance was spotty and informal. Documents that had been collected had been misplaced.

Some accidents include: (1) a 5-inch "Loki" rocket, as part of the Rockoon project, ignited on the deck of a ship in 1952. Loki is an American unguided anti-aircraft rocket based on the WW II German Taifun. Taifun means Typhoon. Loki never saw service in its original role but later found widespread use as a sounding rocket; (2) in 1957 on board the USS KEARSARGE CV33, while loading some 2.25-inch Sub-Caliber Aircraft Rockets (SCAR), one accidentally ignited causing injury to a sailor. This accident was thoroughly investigated and the cause pinpointed to a 1-kW antenna a few feet from the wing of the aircraft involved; (3) the exploder mechanism of the Mk 6 torpedo contained a detonator that on two different occasions detonated when the mechanism was being withdrawn from the torpedo. At that stage of the disassembly, a wire, acting as an antenna was exposed between the exploder and the torpedo.

These kinds of unfortunate events, along with an increasing awareness of the hazard of radio frequency (RF) energy to personnel, brought about the requirement to take corrective action and the requirement for the HERO program, still in existence today.

The HERO program and requirements are applicable to Army devices as well. In early 1960s, Picatinny Arsenal conducted a project to protect EEDs from premature initiation due to RF energy by substituting a phosphatized powdered iron-attenuating plug, an RF-absorbing material, in place of the usual plastic sealing plug. This modification was also introduced into the T24E1 Electric Detonator, M36A1 Electric Detonator, T77 conductive mix, M51 Detonators, M2 Squib, M6 Blasting Cap, the Mk 2 Mod 0 ignition element and the Mk 7 Mod 0 ignition element.

Squibs, ignition elements, and other flame producing devices are subject to accidental electrostatic discharge (ESD) or radiation hazards. In the mid 1960s, NOTS researchers explored a substitute for conventional squibs and fabricated a squib containing magnesium-Teflon®-Viton® A, which is ignited with a bridge wire. It is insensitive to electrical current (no-fire below 5 amps) and produces a 2300 - 2500 °C flame.

On 29 July 1967, a fire started on board the CV29 FORRESTAL aircraft carrier caused by stray voltage, which fired a Zuni rocket from an F-4 aircraft stationed on the carrier deck. It started the conflagration and explosions.

## FLARE DESCRIPTIONS

While China Lake pyrotechnicians were developing a new target augmentation flare, a target flare, a decoy flare or other devices, they assigned a "NOTS Model" designation to the device. When the developmental model later evolved into an engineering development model or a production device, the device was assigned another designation such as a Mk-Mod number. It is impressive that about sixty of these NOTS Model devices were under concurrent development in a window of only a few years.

The Army, Navy, Air Force and commercial developers had similar conventions. Often they assigned their own unique identification to their developments. And sometimes there only was a "part number" assigned related to a contract.

In several instances there is mention of a flare in the literature but only with limited or no information about the device. That explains why in a few cases herein there is a scarcity of details about a given device. In the following section, there are synoptic descriptions of a variety of decoy flares and a few others.

### **T-131 Tracking Flare**

NOTS, China Lake was involved with infrared target augmentation since 1954. They needed a target source for the F6F-5K drone. The T-131 tracking flare developed at NOTS was the first infrared source for drone use. Six to sixteen of these are needed on the F6F-5K drone to provide a suitable signature. The grain most likely consisted of magnesium, Teflon®, and Kel-F® wax.

### **NOTS Model Flare series**

The intent of the following descriptions is to provide a summary of information about the flare design and its intended use. When information is available, its performance capabilities are also provided. The composition of the flare grain is included when available or the composition is referenced to a composition "PL" number, the list of which is included in the Appendix.

**NOTS Model 400A Decoy Flare:** This flare is the forerunner to the EX 46 Mod 0 decoy flare. The NOTS Model 400A decoy flare is intended for launching from an AN/ALE-29 dispensing set. The goal is to defeat the Soviet ATOLL AA-2 air-to-air missile. The flare's composition consists of 55% magnesium, 30% Teflon®, and 15% Viton® A. The design includes a pull wire for ignition, which is similar to pull wire igniters used in some Army devices. Mentioned in 1967 report.

**NOTS Model 700:** With some exceptions, the early NOTS Model 700 flares all contain Kel-F® wax as a binder. Mentioned in 1960 report. The transition from Kel-F® wax to Viton® A in flares started about 1959.

**NOTS Model 701:** This is a tracking flare with a composition that radiates in the visible.

**NOTS Model 701A:** This is a visual tracking flare that later was released as the Mk 21 Mod 0 tracking flare. The Model 702A flare supplanted the NOTS Model 701A flare because the former demonstrated superior background contrast over the NOTS Model 701A flare. The NOTS Model 701A flare grain composition is 54% magnesium, 34% sodium nitrate, and 12% Laminac®.

**NOTS Model 702:** This target tracking flare was designed for attachment to a target missile. The U. S. Flare Division of the Atlantic Research Corporation under a China Lake contract developed this flare. The device has a steel case of 1-inch outside diameter by 10-inches long and weighs 0.57 pounds. The load weighs 0.26 pounds (120 grams), has an output of about 300 W/sr in the 1.8 $\mu$ m to 2.7 $\mu$ m bandpass region, and has a burning time of 50 seconds. It is ignited with the Navy Mk 1 Mod 0 squib. This is the first application of a flare as a target tracking flare. Clusters of four of these flares are attached to the 5-inch High Velocity Aircraft Rocket (HVAR). The infrared grain composition in this flare is 54% magnesium, 30% Teflon®, and 16% Kel-F® wax. This formula, which has a much higher infrared radiative yield than any previous composition, was discovered in the spring of 1956. The heat of reaction is 2200 calories per gram. The peak flame temperature is in excess of 3200 K at a graybody radiation temperature of about 1800 K. The NOTS Model 702 flare evolved in 1956 from discovery of the new composition. It is the forerunner of all infrared flare decoys. Mr. George T. Hahn<sup>7</sup>, Mr. Paul G. Rivette and Mr. Rodney G. Weldon of NOTS applied for a patent for an Infrared Tracking Flare on 27 August 1958. The infrared composition described in the patent is 54% magnesium, 23% Teflon®, and 23% Kel-F® wax. There are three versions of the NOTS Model 702 flare, these being the NOTS Model 702A flare, the NOTS Model 702B flare and the NOTS Model 702C flare. These differ only in their ignition system.

**NOTS Model 702A:** This target augmentation flare was developed in the spring of 1956 concurrently with the NOTS Model 700 flare. It was developed for augmentation of the signature of the F6F-5K and Ryan KDA-1 Firebee drone (one Continental J69 turbo-jet engine). No less than two NOTS Model 702A flares are used to augment the F9F-6K target per firing pass at 30,000 feet. It is initiated electrically with the Navy Mk 1 Mod 0 squib. The NOTS Model 702A flare has a 2-inch diameter steel case. The infrared composition in the flare is 54% magnesium, 23% Teflon®, and 23% Kel-F® wax. It burns for 60 seconds at ground level and 80 seconds airborne at 65,000 feet altitude. The infrared radiation from the NOTS Model 702A flare equals the infrared radiation from six NOTS Model 701A visual flares. The NOTS Model 702A flare supplanted the NOTS Model 701A flare

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<sup>7</sup> Hahn, George T., Paul G. Rivette and Rodney G. Weldon. Infrared Tracking Flare. U. S. Patent 5,679,92127. October 21, 1997.

because it demonstrated superior background contrast over the NOTS Model 701A flare. The NOTS Model 702A flare was considered to be the Navy Tentative Standard and is interchangeable with the USFC W111B tracking flare, a commercial item made by the US Flare Corporation (USFC), Pacoima California.

**NOTS Model 702B:** This is a target augmentation flare that radiates in the infrared. It is ignited parasitically. Ignition is achieved by the impingement of the rocket-exhaust gases upon milled openings in the flare case, which are covered with plastic tape, on the ignition end of the flare and. The NOTS Model 702B flare was approved for production under the designation of Mk 33 Mod 0 tracking flare. Mentioned in 1960 report.

**NOTS Model 702C:** This target augmentation flare is a combination parasitic and squib initiated flare. Units were tested between sea level and 70,000 feet altitude and performed successfully under all conditions. Mentioned in 1960 report.

**NOTS Model 703:** This target augmentation flare is an experimental device developed by US Flare Corporation under Navy support. It is a slow burning flare with a Teflon® sleeve-case that enters into the reaction to add a significant amount of heat. This flare is 1-inch in diameter by 8-inches long and weighs 0.4 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax and weighs 0.1 pounds (45 grams). It has an output of about 150 W/sr in the 1.8µm to 2.7µm bandpass region, and has a burning time of 90 seconds. The benefit of a case that enters into the reaction only works for long-burning flares wherein the Teflon® has sufficient time to decompose thereby releasing the fluorine for reaction with the magnesium. The NOTS Model 702 flare contains 0.26 pounds of composition but radiates only about half the energy/gram compared to the NOTS Model 703 flare that contains one-third of the amount of composition. Cost of the Teflon® restricted its use in this application. Mr. Allen and Mr. Faldo of China Lake are credited in a 1959 report with management of the development of this flare.

**NOTS Model 704:** This countermeasure flare was developed by NOTS. The requirements included: (1) reliable ignition at Mach 0.5, (2) aerodynamic stability, (3) rise time within 0.5 seconds, (4) kW/sr intensity in the 2.0µm to 3.0µm region, (5) successful decoy action against an infrared seeking missile, and (6) maximum diameter of 1.5 inches. The flare went through a series of design changes from the NOTS Model 704A flare to the final NOTS Model 704K flare. The NOTS Model 704G flare, the NOTS Model 704H flare, and the NOTS Model 704K flare were built by the US Flare Corporation. The pneumatic dispenser was designed and built by the Armour Research Foundation of the Illinois Institute of Technology.

**NOTS Model 704A:** The original NOTS Model 704A flare is 1.5-inches in diameter by 3-inches long. The grain weighs 0.35 pounds (160 grams), has an output of about 1800 W/sr in the 1.8µm to 2.7µm bandpass region, and has a burning time of 9 seconds. This may be the first countermeasure flare to have been developed. The cross-sectional view shows a cartridge with an ogive nose, end-burning

composition in a cavity with first fire and ignition composition on the end fitted with a squib that ejects the contents. The unit is a free-falling finned device with a weighted nose. The flare composition is loaded in the aft end of the fin area. Ignition is by means of a Mk 2 Mod 0 squib that is itself initiated by the current flowing between the contact button on the back end of the flare and the flare case. Mr. Allen and Mr. Faldo of China Lake are credited in a 1959 report with the development of this flare.

**NOTS Model 704B:** This variant is an enlarged version of the NOTS Model 704A flare, which increased the burning time but gave little advantage on a relative weight basis.

**NOTS Model 704C:** This variant used a Teflon® sleeve to contain the flare material. It did not prove effective.

**NOTS Model 704D:** This variant involves an ignition design study to reduce damage to the squib wiring by the windstream.

**NOTS Model 704E:** This variant involved a change in the fin size from 0.5 inches to 0.75 inches to improve aerodynamic stability. This design change was retained in subsequent models.

**NOTS Model 704F:** This variant consisted of a replacement of the granulation of the magnesium from gran 15 (100-200 mesh) to gran 16 (200-325 mesh). This resulted in an increase in intensity with a shorter burning time. It was adopted to compensate for altitude and windstream losses.

**NOTS Model 704G:** In this variant the original solid cone shaped nose was replaced with a hollow ogive shape. Stability was improved and assembly was simplified by this change.

**NOTS Model 704H:** This variant combines the composition of the NOTS Model 704F flare and the configuration of the NOTS Model 704G flare. Flare production and dispenser development contracts to US Flare Corporation and the Armour Research Foundation of the Illinois Institute of Technology were based on this design. This flare is 1.5 inches in diameter by 3 inches long. It has an ogive front end with 4-fins aft. All parts are made from iron. The weight is 1.65 pounds (750 grams). The unit, which is ignited at the aft end, burns for 8 seconds and contains 0.2 pounds (90 grams) of flare composition consisting of 18% magnesium gran 15 (100-200 mesh), 36% magnesium gran 16 (200-325 mesh), 30% Teflon® #1 (30-50 mesh), and 16%, Kel-F® #40 wax.

**NOTS Model 704J:** This variant incorporates an improved squib assembly and mechanical changes to prevent the nose cone from separating from the flare.

**NOTS Model 704K:** This is the final version. It includes a composition change recommended by US Flare Corporation based on studies conducted during the NOTS Model 704H flare developments. This target flare is 1.5 inches in diameter by 3 inches long. It has an ogive front end with four 0.75-inch long fins aft. The case is a finned stainless steel cylinder with ogive nose cone. The device weight is 1.66 pounds (750 grams). The unit is ignited at the aft end, burns for 10 seconds and contains 0.36 pounds (163 grams) of flare composition consisting of 18% magnesium gran 15 (100-200 mesh), 36% magnesium gran 16 (200-325 mesh), 30% Teflon® #1 (30-50 mesh), and 16%, Kel-F® #40 wax.

**NOTS Model 705:** This series of target augmentation flares was developed for drone augmentation. They also are used on the Pogo-Hi rocket. The various electrically ignited versions differ principally in their burning times and radiant intensities. The NOTS Model 705A flare has been shown to ignite and burn at 60,000 feet altitude. This steel cased device is 2.25 inches in diameter by 9.5 inches long and weighs 3.53 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

**NOTS Model 706:** This is a tracking flare with a composition that radiates in the visible. Mentioned in 1960 report.

**NOTS Model 707:** The NOTS Model 707 flare, developed by NOTS, was designed as a high altitude visible tracking flare to augment the Sidewinder 1-C missile signal. It also is used to augment the signature of the Vought KD2U-1 Regulus II drone (one GE J33 jet engine). This drone is larger than the Ryan KDA-1 Firebee drone and consequently needs more flares. The NOTS Model 707 flare was one of the subjects of an elaborate early attempt to establish a correlation between flare burning time performance, composition, and construction of various flares. The device is 1 inch in diameter by 24 inches long and weighs 1.48 pounds. It is ignited parasitically. The grain is assembled into a stainless steel case. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

**NOTS Model 707A:** This is the tracking flare mounted on the Sidewinder 1C missile. The flare must operate at 80,000 feet altitude. The flare is about 1-inch in diameter. It radiates about 300,000 candela in the visible region for 30 seconds when tested at ground level.

**NOTS Model 709:** This is a tracking flare with a composition that radiates in the visible. Mentioned in 1960 report.

**NOTS Model 710:** This target augmentation flare, designed by NOTS, is enclosed in a Teflon® sleeve that probably contributes to the efficiency of the flare's performance under ground test conditions. However, under experimental flight tests, the low friction between the Teflon® sleeve and the pellet led to grain separation. To overcome this deficiency, a metal sleeve was substituted and performance was then acceptable to 30,000 feet altitude. The flare is ignited

electrically and is used to augment drone signatures. The device is 2 inches in diameter by 9.75 inches long and weighs 1.85 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

**NOTS Model 711:** This target augmentation flare is in a plastic case and is used to augment the radiative signature of target drones. The Air Force nomenclature for this flare is TAU-15/B. Some references state that the TAU-15/B infrared tracking flare is the Air Force tentative standard of the NOTS Model 711A flare. Mentioned in 1960 report. This target flare was developed by NOTS in response to an Air Force Interservice request to China Lake for the production of 500 target flares of defined characteristics in terms of size, radiant energy and altitude performance. The flare was designed and fabricated with a modified manufacturing procedure using the NOTS Model 702A target flare composition. The initial configuration delivered to the Air Force is designated the TAU-15/B flare. The Navy modification is designated the MK 28 Mod 0 flare. The grain is assembled into a Micarta phenolic case. Ignition is performed electrically with the Mk 2 Mod 0 squib. The device is 1.93 inches in diameter by 9.5 inches long and weighs 1.5 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax. The first fire is a mixture of 90% barium chromate and 10% boron powder.

**NOTS Model 711A:** This target augmentation flare is in a plastic case and is the first flare used for evaluation of weapon systems. The developmental objective of this flare is to provide infrared augmentation to Air Force aerial tow targets and drone aircraft. The USN also used it on drone aircraft, target rockets, and aerial towed targets to provide better evaluation tests for the Sidewinder and Falcon missiles. This target flare was mounted on an F6F-5K aircraft. The Prototype Production for Evaluation (PPE) of this flare was conducted at NAD Crane. The NOTS Model 711A flare aka the TAU-15/B infrared tracking flare evolved into the Mk 28 Mod 0 target flare. Mentioned in 1960 report.

**NOTS Model 712:** This target augmentation flare is in a plastic case and is mounted on the wing tip of fighter aircraft that are configured as a drone. The airborne burning time is 120 seconds. Mentioned in 1960 report.

**NOTS Model 712A:** This electrically ignited device, developed by NOTS, is used as a target augmentation flare for testing the increased range Sidewinder 1C missile. It is attached to the QF-9F target drone, the Beech Aircraft KDB drone or the Ryan target drone BQM-34A (old designation Q2C) jet powered aerial target with a subsonic speed. The flare has an airborne burning time of 60 seconds and when airborne radiates 1300 W/sr in the 2 $\mu$ m to 3 $\mu$ m bandpass region. On the ground, it radiates about 2000 W/sr in the 2 $\mu$ m to 3 $\mu$ m bandpass region for about 45 seconds. The device is 2-inches in diameter by 12 inches long and weighs 2.36 pounds. The composition contains 54% magnesium gran 15, 30% Teflon® no. 1, and 16% Kel-F® #40 wax. Its phenolic case eliminates the problem of molten metallic particles dripping from the case during combustion. The flares for a missile test were loaded at the Naval Ordnance Plant in Macon Georgia. During a conference in 1960, Mr.

James H. Pennington of China Lake stated that the NOTS Model 712A flare would become the NOTS standard target source for most target drones. The NOTS Model 726C flare replaced the NOTS Model 712A flare. Mr. Allen of China Lake was involved in the development of the NOTS Model 712A flare.

**NOTS Model 712C:** This target augmentation flare is parasitically ignited.

**NOTS Model 712E:** This target augmentation device has greater reliability, increased radiancy, and improved altitude performance compared to the NOTS Model 712 flare and the Flare-Northern W211S flare. The NOTS Model 712E flare also has increased output and storage life. It uses NOTS Model 712A flare hardware and has Viton® A in the composition. Compared to the NOTS Model 712A flare, the NOTS Model 712E flare burns much longer and the radiative output in the 2µm to 3µm bandpass region is almost double at 60,000 feet altitude. Its infrared signal is sufficient for Sidewinder 1C missile firings at high altitudes and long standoff ranges. The composition contains 54% magnesium gran 16, 30% Teflon® no. 1, and 16% Viton® A. This flare composition is reported to be extremely resistant to moisture deterioration and is readily ignitable at high altitude. Initiation is with a NOTS Model 39A pyrogen squib or E. I. Dupont E-92 blasting cap. It does not have an intermediate ignition composition or first fire composition.

**NOTS Model 713A:** This is a high altitude flare for the Sparrow III missile, which was developed by the Bermite Powder Company, Saugus California for the Navy Bureau of Ordnance during 1960. This parasitically ignited flare emits 200,000 candela and has a burning time of 30 seconds at 70,000 feet, the operational altitude. The flare contains 245 grams of illuminating composition consisting, in parts by weight, of 60 parts gran 17 atomized magnesium, 5 parts gran 16 atomized magnesium, 40 parts sodium nitrate, and 5 parts Laminac® polyester binder catalyzed with Lupersol™ DDM. The first fire is a mixture of 10% boron and 90% barium chromate. The complete flare weighs about one pound and is two inches in diameter by four inches long.

**NOTS Model 714A:** This is a Bullpup missile parasitic tracking flare designed for visual tracking. It was developed as a result of a 1957 directive from Navy Headquarters in Washington DC. It replaces the Mk 23 Mod 0 electric tracking flare. The cartridge is 1.75 inches diameter by 6 inches long with a cartridge wall thickness of 0.5 inches. It burns about 47 seconds with visible intensity of 140,000 candela in the first 10-12 seconds and 225,000 candela thereafter. The high-intensity composition is a mixture of strontium nitrate, sodium nitrate, magnesium, and Laminac® 4116, the latter being a polyester binder. For low-intensity, hexachlorobenzene is added and potassium nitrate replaces the sodium nitrate. This flare evolved into the Mk 27 Mod 0 tracking flare.

**NOTS Model 715B:** This target flare was developed by NOTS to fit the AN/ALE-18 pneumatic chaff dispenser installed on A3-D, A3-J, and F4-D aircraft. The 0.63-pound (285 gram) flare pellet is extruded into a wedge shape of 3.65 inches by 2.7

inches by 1.05 inches thick, which tapers to 0.34 inches thick. An ignition composition is buttered on all surfaces. It is initiated with a NOTS Model 668A stab primer. The flare burns about 8 seconds. The magnesium-Teflon®-Kel-F® wax flare mixture had inadequate physical properties when extruded which caused a composition change to composition PL 6239: 54% magnesium gran 16, 30% Teflon® #7, and 16% Viton® A. The device weight is 0.8 pounds (370 grams). About 35 composition variants were evaluated during the flare development. Granular sizes of the magnesium and Teflon® were the main parameters varied in the study. Mr. Allen and Mr. B. A. Breslow of China Lake reported this flare in 1964. The NOTS Model 715B flare evolved into the Mk 43 Mod 0 flare.

**NOTS Model 717B:** Flare. No further information was found.

**NOTS Model 719:** This target augmentation flare, developed by NOTS, is a cylindrical aluminum cased flare developed for use with the Sidewinder 1C missile. It was tested in flight at altitudes up to 50,000 feet. The device is 1 inch in diameter by 18 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

**NOTS Model 720:** This target augmentation flare, developed by NOTS, was intended for use on the Radioplane XKD4R-1 target drone. The flare is assembled in a phenolic ablation sleeve in sets of four, which burn consecutively to provide a signal of the required duration. Each flare actuates a thermal switch as it approaches burnout, to initiate the next flare. The device is 1.35 inches in diameter by 11 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

**NOTS Model 723:** This target augmentation flare, developed by NOTS China Lake before 1974, is one of the largest magnesium-Teflon® flares ever constructed. Only two flares were ever built. The units are ignited electrically. Viewed in a vertical static test, the flare yielded 186 kW/sr over a 60 second period. There is no case material. The device is 12 inches in diameter by 16 inches long and weighs 70 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

**NOTS Model 724A:** This is a curved tracking flare whose special design shape was requested by NOL White Oak in the mid 1960s. The flare is needed for tracking and recovery of a canister. It has a 30 second burning time and produces 16,000 candela at 65,000 feet altitude for visual tracking. The curved shape saves space in the canister. The flare fits into and marks the path of an instrumentation package that is ejected from a missile at altitudes up to 100,000 feet altitude. Initiation is by a hand grenade bouchon. Its predecessor is the NOTS Model 739A flare. Another reference describes this curved flare as the NOTS Model 742 flare. The latter seems more likely since the curved flare design is a follow-on to the NOTS Model 739A, the NOTS Model 742 being numerically more logical to be a follow-on to the NOTS Model 739.

**NOTS Model 726 series:** This target augmentation flare is a wing tip target flare developed to augment the QF-9C target drone and the Q-2C target drone for the Sidewinder 1C missile. This flare is also identified with the Beech KDB drone. It was designed for operation at 50,000 feet and Mach 0.9. The NOTS Model 726A flare and the NOTS Model 726B flare differ both in size and composition, the NOTS Model 726B flare possessing twice the burning rate of the NOTS Model 726A flare with a correspondingly higher radiant intensity.

**NOTS Model 726A:** This target augmentation flare was developed under the guidance of Mr. Allen of China Lake to satisfy the need for increased radiation and better high altitude performance when attached to a QF-9F target drone or a BQM-34A (old designation Q2C) jet powered aerial target operating at subsonic speed. The flare is used to test the Sidewinder 1C missile. It was designed to perform at Mach 0.9 and at 50,000 feet altitude. The flare needed to perform better than the NOTS Model 712A flare or the Flare-Northern W211S flare. It has a one-piece extruded grain that has a composition formula different from that in the NOTS Model 726B flare. It is two-inches in diameter by 12 inches long and is electrically ignited. Extrusion of the grain in comparison to pressing the grain eliminated output fluctuations and ejection of increments. The burning time is about 4 minutes at 30,000-foot altitude. The NOTS Model 726A flare, NOTS Model 726B flare, and NOTS Model 726C flare differ in the type of Teflon® used. Each is inhibited with a different material.

**NOTS Model 726B:** This target augmentation flare was developed under the guidance of Mr. Allen of China Lake to satisfy the need for increased radiation and better high altitude performance when attached to a QF-9F target drone or a BQM-34A (old designation Q2C) target drone. The flare has a one-piece extruded grain that has a formula different from that in the NOTS Model 726A flare or the NOTS Model 726C flare. It is 2.25 inches in diameter by 8 inches long and is electrically ignited. It uses a NOTS Model 39A pyrogen squib to get better very high altitude ignition. The NOTS Model 726B flare was produced at the Navy Propellant Plant (NPP), Indian Head Maryland and was programmed to replace the NOTS Model 712A flare. However, the cast polyester inhibitor proved inadequate for flight when one was observed to break apart. The burning rate is twice that of the NOTS Model 726A flare and emits twice the amount of infrared radiation. The NOTS Model 726A flare, the NOTS Model 726B flare, and the NOTS Model 726C flares differ in the type of Teflon® used. Each is inhibited with a different material.

**NOTS Model 726C:** This target augmentation flare was developed under the guidance of Mr. Allen of China Lake to satisfy the need for increased radiation and better high altitude performance when attached to a QF-9F target drone or a BQM-34A (old designation Q2C) jet powered aerial target operating at subsonic speed. The flare is used to test the Sidewinder 1C missile. It was designed to perform at Mach 0.9 and at 50,000 feet altitude. The flare needed to perform better than the NOTS Model 712A flare or the Flare-Northern W211S flare. After evaluation, it was determined that the NOTS Model 726C flare design would replace the NOTS Model

712A target augmentation flare because the former does not eject burning materials during operation. The NOTS Model 726C flare has a one-piece extruded grain and a composition formula different from that in the NOTS Model 726A flare or the NOTS Model 726B flare. It is 2.16 inches in diameter by 12 inches long and is electrically ignited. At ground level, the NOTS Model 726C flare burns about 40 seconds. The NOTS Model 726A flare, the NOTS Model 726B flare, and the NOTS Model 726C flares differ in the type of Teflon® used. Each was inhibited with a different material. The inhibitor on the NOTS Model 726C flare is glass cloth and Ethocel tape. The production quantities were made at the Navy Propellant Plant, Indian Head Maryland.

**NOTS Model 727:** The NOTS Model 727 target augmentation flare, developed by NOTS, is wing tip mounted on the Curtis Wright Skydart drone. The unit is 2 inches in diameter by 10 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

**NOTS Model 728A:** This is a ballistic target rocket flare used in Sidewinder 1C tests. The device is designed for high altitude performance. This model is electrically ignited and packaged in a 2-inch diameter by 12-inch long case. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax. At ground level, it radiates about 2000 W/sr in the 2µm to 3µm bandpass region for about 30 seconds. At an altitude of 60,000 feet, it burns for 60 to 65 seconds.

**NOTS Model 728B:** This is a ballistic target rocket flare used in Sidewinder 1C tests. The device is designed for high altitude performance. This model is parasitically ignited and is packaged in a 2-inch diameter by 12-inch long case. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax. At ground level, it radiates about 2000 W/sr in the 2µm to 3µm bandpass region for about 30 seconds. At an altitude of 60,000 feet, it burns for 60 to 65 seconds. This variant was launched vertically at 47,000 feet altitude from an F-4 aircraft and functioned successfully up to 82,000 feet altitude.

**NOTS Model 729:** The NOTS Model 729 target augmentation flare, designed by NOTS, was initially developed as an augmentation flare for use with the Beech XKD2B-1 target drone. It was designed for sustained operation at high altitude (70,000 feet). This flare is intended to replace the 5B1-5.1 Special Devices infrared target augmentation flare made by Special Devices Incorporated, Newhall, California for a Beech Aircraft Corporation Navy drone. The Beech Aircraft Corporation's XKD2B-1 Navy drone later became the AQM-37A expendable powered target drone. At 70,000 feet altitude, the flare is required to provide ample infrared radiation in the 2µm to 3µm and 3µm to 5µm electromagnetic bands for 8 minutes. Test failures of the NOTS Model 729 flare lead to development of improved models. China Lake was requested by Navy Headquarters in Washington DC to develop a backup to the Special Devices 5B1-5.1 flare in the event that the latter did not meet requirements. The resulting three developmental models are:

NOTS Model 729A flare uses composition PL 6239.

NOTS Model 729B flare uses composition PL 6328.

NOTS Model 729C flare uses composition PL 6382.

The improved models also differ in the type of Teflon® used. The composition in each is extruded to form the grain. The ignition mixture and first fire composition consist of a mixture of 10% boron and 90% barium chromate. Of the three compositions, the NOTS Model 729B flare was selected for further development on the basis of high altitude performance.

**NOTS Model 729B:** This is a target augmentation flare for the AQM-37A target drone. It was developed as a back up to the commercially manufactured infrared flare, the Mk 37 Mod 0 tracking flare. It is 20.25 inches long by 2.5 inches in diameter. Because of its 20.25-inch length, the flare mounting incorporates a constant force spring that advances the flare grain continuously as it burns. The grain, which is extruded MTV, is inhibited with a spiral wrap of ethyl cellulose tape. The grain is formulated with composition PL 6328. The first fire is a mixture of 10% boron and 90% barium chromate. Ignition is accomplished electrically. The NOTS Model 729B flare, as compared to the NOTS Model 729A flare and the NOTS Model 729C flare, has the fastest burning rate at 70,000 feet altitude with the greatest output in the 2µm to 3µm bandpass region. The NOTS Model 729B flare is similar in configuration to the Mk 37 Mod 0 flare but not in composition.

**NOTS Model 733A:** This target flare was developed about 1962 under the guidance of Mr. Allen of China Lake as an infrared flare to protect the Ryan BQM-34A jet powered aerial target drone. A specific requirement was that the flare must ignite and burn at very high altitude and high subsonic Mach number. In addition, the flare needs to be compatible with the Lundy Model RC17-101 mechanically operated miniature chaff dispenser and the electrically operated Lundy Model 30-0011-2 chaff dispenser that were installed in either wing of the BQM-34A aerial target. These dispensers originally were designed to dispense RR-72 flare cartridges. The NOTS Model 733A flare is also compatible with the AN/ALE-33 dispenser. The flare format, similar to the RR-72 flare cartridge, is extruded in a rectilinear shape 4.875 inches long by 3 inches wide by 1.031 inches thick. The flare weighs 0.725 pounds. The grain is composition PL 6328. Ignition takes place over the entire surface area. At 47,000 feet altitude and Mach 0.86, the grain burns for about 6 seconds. To obtain reliable ignition, a wind-removable pull-away tab device operated by the air stream activates the NOTS Model 668A stab-initiated primer, which in turn ignites the intermediary Z-2 heat paper and that in turn ignites the extruded grain. The NOTS Model 733A flare exceeds the output and burning time required for operation at 50,000 feet altitude. Release to Prototype Production for Evaluation occurred in June 1965. It became the Mk 42 Mod 0 target flare.

**NOTS Model 733B:** This target flare was developed in the mid 1960s to fit a chaff dispenser on the BQM-34A (Q-2C) target drone.

**NOTS Model 736:** This cylindrical target augmentation flare, fabricated by NOTS, is a target flare for use with the Redeye missile. The flare is 0.56 inches in diameter by 8.75 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

**NOTS Model 737:** This cylindrical target augmentation flare, fabricated by NOTS, is a target flare for the Redeye missile. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A. The flare is 0.79 inches in diameter by 8.75 inches long.

**NOTS Model 739A:** In the mid 1960s, NOL White Oak requested the design of a flare for tracking and recovery of a canister containing an instrumentation package. It was made to fit into and mark the path of an instrumentation package ejected from a Blue Rock missile at altitudes up to 100,000 feet. The flare is 1 inch in diameter by 10 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A. Later a curve-shaped flare, the NOTS Model 724 flare, was developed to save space in the canister. Another reference states the follow-on is the NOTS Model 742 flare, which most likely is the correct nomenclature.

**NOTS Model 740:** This cylindrical target augmentation flare, fabricated by NOTS, is a modified NOTS Model 737 flare designed for use as a Redeye missile target. The NOTS Model 740 flare incorporates a tubular steel shield to suppress visible radiation. The flare is 0.79 inches in diameter by 8.75 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

**NOTS Model 741:** This cylindrical target augmentation flare, fabricated by NOTS, is a target flare designed for use as a Redeye missile target. The NOTS Model 741 flare incorporates a tubular steel shield to suppress visible radiation. It is similar in composition to the NOTS Model 737 flare but has the shield design of the NOTS Model 740 flare. The flare is 1 inch in diameter by 36 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

**NOTS Model 742:** In the mid 1960s, NOL White Oak requested the design of a flare for tracking and recovery of a canister containing an instrumentation package. That earlier design is the NOTS Model 739A flare.

Later a curve-shaped flare, perhaps erroneously designated the NOTS Model 724A flare, was developed to save space in the canister. Another reference describes this curved flare as the NOTS Model 742 flare. The latter designation seems more likely since the curved flare design is a follow-on to the NOTS Model 739A, the Model NOTS 742 being numerically more logical to be a follow-on to the NOTS Model 739.

NOTS fabricated this curved-shaped tracking flare, the NOTS Model 742 flare. It was made to fit into and mark the path of an instrumentation package ejected from a Blue Ridge missile at altitudes up to 100,000 feet. It has a 30 second burning time

and produces 16,000 candela at 65,000 feet altitude for visual tracking. The curved shape of the flare saves space in the canister. Initiation is by a hand grenade bouchon. The flare is configured as a 10-inch long by 1-inch diameter cylinder that is curved in a 115-degree arc in about a 5-inch radius. This curved cylinder contains a grain that consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

**NOTS Model 743:** This is a tracking flare for the anti-radiation AGM-45A Shrike missile to obtain missile trajectory. It is marginal in the required luminosity.

**NOTS Model 743A:** This tracking flare is intended for use on the anti-radiation AGM-45A Shrike missile to obtain missile trajectory. The case is an 11-inch long aluminum tube of 1-inch outer diameter and 0.930 inch inside diameter. It contains an extruded grain with composition PL 6239. This unit was evaluated for use on the Shrike missile because of problems with the commercial W114B tracking flare.

**NOTS Model 743B:** This tracking flare is intended for use on the anti-radiation AGM-45A Shrike missile to obtain missile trajectory. The case is an 11-inch long mild-steel tube of 1-inch outer diameter and 0.930 inch inside diameter. It contains an extruded grain with composition PL 6239. This unit was evaluated for use on the Shrike missile because of problems with the commercial W114B tracking flare.

**NOTS Model 744:** This tracking flare has more luminosity than the NOTS Model 743 flare.

**NOTS Model 745:** This tracking flare is larger in diameter and has an increased radiancy over the NOTS Model 743 flare and the NOTS Model 744 flare.

**NOTS Model F28-1:** This is an MTV target flare mounted on the AQM-37 non-recoverable drone. The flare faces forward into the windstream and is ignited at Mach 1.5 at 60,000 feet altitude. It has a burning time of 90 seconds. Four flares are burned simultaneously to obtain the required intensity levels. The external dimensions are 2 inches in diameter by 23 inches long. The grain composition is 63% magnesium, 10% graphite, 13.5% Teflon® #7, and 13.5% Viton® A.

**NWC Model F28-2:** This decoy flare incorporates the latest advances in igniter and grain design resulting from the EX 49 Mod 0 flare development. The NWC Model F28-2 flare is compatible with the AN/ALE-29A dispenser and the AN/ALE-39 dispenser and is designed to be a flare with the burning time and radiant intensity needed by medium performance attack aircraft in a low altitude, high-subsonic-flight-speed environment. The change from the NOTS Model designation to the NWC Model designation most likely is the result of the name change of China Lake from NOTS to NWC about 1969.

**NOTS Model F28-2A:** This MTV countermeasure flare is similar in physical dimensions to the Mk 49 Mod 0 flare. A modified formula is used to increase the burning time by a factor of two over the Mk 49 Mod 0 flare. The external dimensions

are 1.42 inches in diameter by 5.8 inches long. The flare weighs 0.52 pounds. The grain dimensions are 1.33 inches in diameter by 4.87 inches long. The grain weighs 0.34 pounds.

**NOTS Model F28-2B:** This experimental MTV countermeasure flare is dimensionally identical to the NOTS Model F28-2A flare but with a different unspecified composition to modify the burning time.

**NWC 45/01 Countermeasure Flare:** The NWC 45/01 flare is a revisited version of the Mk 49 Mod 0 flare. The configuration resembles the spaghetti flare design of the MK 49 Mod 0 flare but is much larger. It is stated to have a very fast rise time, a high infrared intensity and a 50% longer burning time than the Mk 49 Mod 0 flare. The grain consists of 63% magnesium, 13.7% Teflon® #7, 10% graphite and 13.5% Viton® A. The grain is 2.88 inches in diameter by 8.37 inches long and weighs 2.7 pounds.

**Navy Mini-Flare:** The Navy mini-flare is similar in configuration and intended application to the Army XM-196 mini-flare. The MTV formula in the Navy flare is different from that in the Army mini-flare. The design was not released for procurement. The external dimensions are 1.05 inches in diameter by 2.63 inches long. The device weighs 0.21 pounds. The grain dimensions are 0.94 inches in diameter by 1.88 inches long. The grain weighs 0.066 pounds. Slightly different dimensions appear in other reports. The grain formula is 54% magnesium, 30% Teflon® and 16% Viton® A. The composition is pressed to make the grain. The development of the Navy mini-flare is described in more detail in the section entitled Mini-Flare Development.

### UK Flare

**UK Mk 1 Decoy (an earlier UK designation is Flare Type E/2/1):** The UK decoy unit identified as Flare Type E/2/1 later became the UK Mk 1 Decoy about March 1963. It is 2.25 inches in diameter by 5.3 inches long. The 1962 vintage units contain a safe and arming device (S&A). The grain infrared composition consists of 55% magnesium and 45% Teflon®. There is no binder in this composition. Without a binder, this composition cannot be extruded but must be pressed to form the grain. The grain has longitudinal grooves on the outer surface. When ignited, it produces a rise time to peak intensity of 0.5 seconds.

## Army Devices

**M-50 Tow Target Flare:** This Army flare provides a target for both night and day practice firing of antiaircraft guns. It is 22.8 inches in length by 2.62 inches in diameter and weighs 7.13 pounds.

**M-76 Airport Flare:** This Army flare is 31.33 inches long by 4.26 inches in diameter and weighs 27.6 pounds. It contains 20-pounds of illuminating composition. It is used for illumination of aircraft landings in case of power failure at the airport.

**M-112 Cartridge:** The case of this cartridge was used as the test vehicle for the development of the RR-77 flare. The M-112 cartridge designation normally is associated with a photoflash cartridge. It is 1.57 inches in diameter by 7.73 inches long.

**M136 (T131) Tracking Flare:** The M136 flare has a laminated phenolic body and an aluminum shank. The illuminating composition in the flare produces 70,000 candela for 75 seconds.

**M-206 Aircraft Decoy Flare:** This is an Army flare, which nominally is 1-inch by 1-inch by 8-inches in size. It is used by both fixed and rotary-wing aircraft.

**XM-196 Mini-Flare (Army):** This is the designation for the experimental mini-flare assigned by the Army. The MTV composition is pressed to make the grain. A Picatinny Arsenal task under an Electronics Command, Fort Monmouth directive calls for the development of the Army mini-flare. Tracor developed the decoy system with the flare production assigned to the Pace Corporation. The flare dispenser contains 154 flares. The Army mini-flare has a fast rise time and tends to show two peaks, the normal one at maximum radiant intensity and the other one at burnout. The burnout peak is attributed to disintegration of the flare with the exposure of a large reactive surface. The Army mini-flare is a precursor of the Navy mini-flare, which is somewhat similar in design. The external dimensions of the flare are 1.05 inches in diameter by 2.75 inches long. It weighs 0.16 pounds. The grain dimensions of the flare are 0.94 inches in diameter by 1.88 inches long. It weighs 0.066 pounds. Two Picatinny Arsenal compositions are pressed in the case as a single increment. The two compositions, in parts by weight, are: (1) 74 parts magnesium, 26 parts Teflon®, and 2.6 parts Viton® A; and (2) 74 parts magnesium, 26 parts Teflon®, and 2.6 parts nitrocellulose.

**XM-197 Decoy Flare:** Picatinny Arsenal developed this flare designed for release from the hand-held AN-M8 pyrotechnic pistol. This MTV Army Flare is similar to the Mk 50 Mod 0 flare. The device is 1.57 inches in diameter by 3.85 inches long. The grain is 1.25 inches in diameter by 2.4 inches long.

**33-18 Flare:** This is an Army developmental flare intended for ship protection.



## Air Force Flares

**ALE-11 Flare:** The grain in this flare is MTV. It is available in two configurations; 1 inch by 3 inches by 5 inches and 2 inches by 3 inches by 5 inches.

**ALE-11 Flare, Cast Variant:** This experimental flare variant was manufactured about 1966 at Flare-Northern Division of the Atlantic Research Corporation Saugus California by Dr. Hal R. Waite and Mr. Jerry A. Reed for the AN/ALE-25 Dispenser. The flare weighs 2.2 pounds, incorporates a mechanical safe-and-arm initiator, and is loaded with a castable fluoromethacrylate-magnesium composition.

**ALA-17 Flare:** This is an MTV flare that evolved from the RITA-II flare, which has a similar composition but is fractionally smaller in diameter. Picatinny Arsenal developed the ALA-17 flare for the Air Force. The FW-306 infrared composition is pressed to make the grain that is about 2.4 inches in diameter and 4.9 inches long. The ALA-17 flare is about 2.5 inches in diameter by 5 inches long and weighs 1.3 pounds. The ALA-17 flare rise time of two seconds to reach 75% of peak is considered to be too long. This flare is dispensed from an AN/ALE-14 countermeasure flare ejector mounted in the B-52 bomber.

**ALA-17 Flare, Improved Cast Variant:** The improved ALE-17 flare for the AN/ALE-20 ejector set was developed by Dr. Waite and Mr. Reed of Flare-Northern during 1966. An internal burning grain is cast directly into an aluminum case, and, unlike the standard ALA-17 flare, it remains within the case while burning. The core design is a regressive burning internal star. Fluoroalkylmethacrylate is the casting resin.

**ALA-34 flare:** This is an MTV flare that contains infrared composition FW-306. The grain for the ALA-34 flare carries the designation RR-138 grain. The goal is to reach nominally 2000 W/sr in 0.1 seconds and a peak of about 5000 W/sr in 0.3 seconds. The ALA-34 flare is a B-52 flare designed to be dispensed from the AN/ALE-20 Flare Dispenser. There are two variants. One variant designated ALA-34 DL is 10 inches long, twice the length of the ALE-17 flare and 2.4 inches in diameter. In this variant, the grain has a smooth surface. The other variant designated ALA-34G has a larger diameter of 2.66 inches by 4.9 inches long and has a grain with 26 grooves milled along the longitudinal surface. These grooves are filled with an igniter composition. The grooved version exhibited a significantly faster rise time while the double length version exhibited significantly more radiant intensity than the ALA-17 standard flare. Mr. Charles A. Knapp of Picatinny Arsenal initiated the decoy designs under a contract from Eglin Air Force Base.

**RR-72 Decoy Flare:** The external configuration is similar to the NOTS Model 733A target flare.

**RR-77 Decoy Flare:** Multiple RR-77 flares are assembled into the cartridge. The cartridge is placed into the assembly housing of the AN/ALE-14 ejector system. The latter is installed in bomber aircraft. The flares in the cartridge are ejected

sequentially. RITA flare technology utilizing infrared compositions is used for the RR-77 flare development.

**RR-78/ALE Flare Ejector:** This ejector is believed to be the RITA flare battery dispenser.

**RR-80 Decoy Flare:** This flare is designed for use with the AN/ALE-14 dispenser in the B-47 bomber and the AN/ALE-20 dispenser in the B-52 bomber. The composition in the RR-80 flare consists of 66.1% magnesium RMC200, 22.6% Teflon® #5, and 11.3% Teflon® #7. There is no binder in this formulation. The composition is pressed into pellets 4.469 inches long by 2 inches in diameter. The pellets are encased in a polyurethane foam inhibitor. The RR-80 flare consists of two pellets, which in total weigh 1.79 pounds. The flare external dimensions are 2.25 inches in diameter by 10 inches long. The total device weight is 2.63 pounds. The flare pellets burn simultaneously on each end (double ended burning). The burning time at ground level is 25 seconds. Dr. Sidney Katz, Armour Research Foundation of the Illinois Institute of Technology, Chicago developed the RR-80 flare, which is assembled into the RR-80/ALE flare assembly. The latter has 8 tubes and one RR-80 flare per tube yielding a total of eight flares per assembly. The flare assembly ejector set is the RR-80(XY)/ALE which is compatible with the AN/ALE-14 ejector system and AN/ALE-20 ejector systems.

**RR-81 Decoy Flare:** This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber respectively. The RR-81 flare pellet is about 1.875 inches in diameter by 5.75 inches long and contains a composition, in parts by weight, of 31 parts magnesium, 59 parts Teflon®, and 19 parts titanium to which 34 grams of Kel-F® wax is added as a binder. The flare pellet burns simultaneously from the middle toward each end causing the two flames to impinge upon each other. (Opposed end burning) The burning time at ground level is 17 seconds. Kilgore, Incorporated developed the flare. The RR-81 flare is assembled into the RR-81(XY-1)/ALE flare assembly, which has seventeen 11.5-inch tubes and 2 flares per tube.

**RR-82 Decoy Flare:** This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber respectively. The RR-82 flare is about 1.88 inches in diameter by 11 inches long and contains a composition consisting, in parts by weight, of 50 parts magnesium, 40 parts Teflon®, and 10 parts titanium. The flare pellet only burns on one end. The burning time at ground level is 10 seconds. The cartridge has "pop-out" drag fins to partially control the trajectory. This design may have been the first so-called aerodynamic flare decoy. The Universal Match Corporation, Saint Louis Missouri developed this flare. The RR-82 flare is assembled into the RR-82(XY-1)/ALE flare assembly, which has seventeen 11.5-inch tubes and 1 flare per tube.

**RR-88 "Balls of Fire" Decoy Flare:** This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber

respectively. The carbon shell on the RR-88 flare contains a thermite composition consisting of 22.5% aluminum, 76.5% tungsten oxide and 1% Teflon®-7X. This design is also known as the Balls of Fire (BOF). The burning time at ground level is 30 seconds. The flares are assembled into the RR-88(XY-1)/ALE flare assembly, which has 2 tubes and 2 flares per tube. The Balls of Fire flare is discussed further in the section entitled Balls of Fire Decoy (BOF).

**RR-88(XY-1)ALE Flare Assembly:** This flare assembly is for the B-52 bomber. The dispenser concept contains two ejection tubes. Each tube has two BOF flares encapsulated with polyurethane foam in a metal capsule.

**RR-96 Countermeasure Flare:** This nomenclature has been applied to two different countermeasure flare configurations. One flare, 1.13 inches in diameter by 5.25 inches long, is used as a payload in a 2-stage SPAROAIR sounding rocket. Sixteen of these flares are fitted into the nose cone. Dr. Raison at the Armour Research Foundation of the Illinois Institute of Technology was the project engineer. The other flare is used in the nose of the ALE-9 forward launch chaff rocket system. The rocket is the XADR-9A countermeasures rocket developed by Tracor, Austin Texas.

**RR-98 Decoy Flare:** This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber respectively. The RR-98 flare, which is similar to the RITA-I flare, was developed for the RR-98(XY-1)/ALE flare assembly. The flare burns on all surfaces for 6 seconds at ground level. The grain is 1.88 inches in diameter by 5.75 inches long. The grain composition is 54% magnesium, 44% Teflon® and 2% nitrocellulose. The RR-98 flare is a joint development by Picatinny Arsenal and Lambert Engineering Company.

**RR-98(XY-1)/ALE Flare Assembly:** (Quick Response Capability QRC-87): This assembly, named Mfg. Model 103, has 17 tubes with two RITA-I flares per tube. The assembly is called a cartridge when the flares are loaded in the tube.

**RR-98(XY-1)/ALE Flare Assembly-Variant:** This assembly has six tubes with two flares per tube. A flare similar to the RITA-II flare was developed for the RR-98(XY-1)/ALE Flare Assembly-Variant. The flare burns on all surfaces for 6 seconds at ground level.

**RR-108 Grain:** This is the MTV flare grain for the ALA-17 flare.

**RR-115 Flare:** This is a 2-inch by 3-inch by 5-inch rectilinear flare manufactured by the Armour Research Foundation of the Illinois Institute of Technology. It fits the USAF 669A Phase I dispenser. All RR-115 flares contain pressed MTV compositions, an Epon case, a mechanical inertial igniter and a Pyrocore ignition train.

**RR-115 Type I Flare:** The RR-115 Type I flare is a composite of two low-density pellets in an Epon case, which remains intact during functioning. The Type I uses three consecutively burning compounds in the double-end burning epoxy inhibited pellet. The RR-115 Type 1 flare exhibits a rapid rise to a high intensity in 2 seconds which then levels to about 10 seconds burning time. The device weighs 1.34 pounds. The grain composition is 66% magnesium and 34% Teflon. The first fire slurry, in parts by weight, is 57.1 parts barium chromate, 25.8 parts aluminum, and 74.2 parts tungsten(VI) oxide.

**RR-115 Type II Flare:** The RR-115 Type II flare is nozzled and contains two high-density pellets and an Epon case, which remains intact during functioning. The Type II is double-end burning with a nozzle in each 2-inch by 3-inch face of the non-combustible case. The burning profile has a fast rise and then levels off to 6 seconds. The device weighs 1.34 pounds. The grain composition is 66% magnesium and 34% Teflon®. The first fire slurry, in parts by weight, is 57.1 parts barium chromate, 38.1 parts zirconium, and 4.8 parts nitrocellulose.

**RR-115 Type III Flare:** The RR-115 Type III flare has two low-density pellets, each of which has a large slit filled with first fire material in one of the 2 inch by 3 inch surfaces. It has an Epon case that burns away with the flare. The Type III is double-end burning with a slotted nozzle in each 2-inch by 3-inch face of the inhibited grain. It exhibits a high sharp radiation peak followed by uniform radiation for 4 seconds. The device weighs 1.34 pounds. The grain composition is 66% magnesium and 34% Teflon®. The first fire slurry, in parts by weight, is 57.1 parts barium chromate, 38.1 parts zirconium, and 4.8 parts nitrocellulose.

**RR-119 Flare: Early variant:** This is a 2-inch by 2-inch by 5-inch flare provided by Space Ordnance Systems. It fits the USAF 669A Phase-I dispenser. The composition is pressed to make the grain. Mentioned in a 1968 report.

**RR-119 Flare: Later variant:** This 2-inch thick by 3-inch wide by 5-inches long flare variant is dispensed from the AN/ALE-28 dispenser on an Air Force F-111 aircraft. The composition consists, in parts by weight, of 62 parts magnesium, 38 parts Teflon®, and 2 parts polyester binder. In the mid-1970s, the RR-119 flare was the highest performing flare in production. Mentioned in a 1973 report. The device weighs 2 pounds. It contains the Illinois Institute of Technology Research Institute developed inertial bore-safe igniter parts. The manufacturer is Celesco.

**RR-138 Grain:** This is the MTV flare grain for the ALA-34 flare.

**QRC-127 (subset 10/ALQ-27) Flare Assembly:** This assembly has six tubes with four flare cartridges per tube. A flare similar to the RITA-III was developed for this assembly by Aerojet-General Corp. of Azusa California.

**QRC-127 Flare:** This flare, similar to the RITA-III, was developed at the Aerojet-General Corp. for protection of the B-52 bomber. The flare grain is 2.1 inches long

by 2.6 inches in diameter. The flare is an end-burner, which burns for 7 seconds at ground level. The flare composition is 70% magnesium and 30% Teflon®. The pressed pellet grains are assembled into the aluminum case. Ignition is by electric squib. It is compatible with the AN/ALA-20 dispenser.

**QRC-353 (T)-1 Flares:** Unidynamics/Phoenix Division of Universal Match Corporation Industries developed these Air Force flares. Two flares were developed, the Type I and the Type II.

**QRC-353 (T)-1 Type I Flare:** The Type I flare is compatible with the M-112 photoflash cartridge and the Lambert LA-307A photoflash dispenser. The flare has the external configuration of the M-112 photoflash cartridge and incorporates a bore-safe igniter. The Type I differs mainly in size from the Type II. The M-112 cartridge dimensions are 1.57 inches in diameter by 7.73 inches long. The fully loaded device weight is 0.88 pounds. The grain dimensions are 1.45 inches in diameter by 3.80 inches long. The grain weighs 0.36 pounds and consists, in parts by weight, of 60 parts magnesium, 27.5 parts Halon (G80), 5 parts anthracene, and 7.5 parts Fluorel® (KF2140).

**QRC-353 (T)-1 Type II Flare:** The Type II flare is compatible with the M-123 photoflash cartridge and the Lambert LA-308A photoflash dispenser. The flare has the external configuration of the M-123 photoflash cartridge and incorporates a bore-safe igniter. The Type I differs mainly in size from the Type II. The Type II cartridge dimensions are 2.88 inches in diameter by 8.45 inches long. The fully loaded device weight is 3.22 pounds. The grain dimensions are 2.71 inches in diameter by 4.4 inches long. The grain weighs 1.22 pounds and consists, in parts by weight, of 60 parts magnesium, 27.5 parts Halon (G80), 5 parts anthracene, and 7.5 parts Fluorel® (KF2140).

**TAU-15/B Infrared Target Flare:** This is an Air Force expendable aerial target flare designed to provide an airborne infrared target for utilization in aircrew training and to checkout systems employing infrared seeking missiles. This flare was designed to provide target augmentation for the TDU-4/B, TDU-6/B, TDU-9/B, TDU-15/B, and TDU-17/B tow targets. The US Flare Division of the Atlantic Research Corporation produced the TAU-15/B infrared tracking flare, which is the Air Force tentative standard of the NOTS Model 711A flare. The TAU-15/B flare evolved into the Navy Mk 28 Mod 0 tracking flare.

This decoy has a grain in two different diameters. The diameter is 1.938 inches for about two-thirds of the base end and 1.750 inches diameter for about one-third of the ignition end. The flare is 9.5 inches long without the ignition connector and 10.375 inches with. The electrical ignition system consists of a bayonet connector, a Mk 2 Mod 0 squib and first-fire material. The squib is embedded in 5 grams of first-fire material at the front end of the flare. The order of ignition is squib, first-fire material, and then main illuminant. The main illuminant composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® #40 wax.

The composition details as of 1958 are: The first fire material is 10% amorphous boron and 90% barium chromate. The main illuminant, pressed in five increments, is 54% magnesium gran 15, 30% Teflon® no. 1 (E. I. Dupont Chemical Company powder BD 500) and 16% Kel-F® wax (Kellogg Chemical Corporation). This composition is based on the composition in the NOTS Model 702A flare and is also known as the NOTS Standard Composition.

The flare consists of a linen impregnated tube filled with pellets and first fire. The outside diameter is 1.94 inches. The unit weighs 1.58 pounds. After the metal sleeve is added, the flare case's outside diameter is 2 inches including the 6-inch long metal external sleeve by 10.250 inches long. The metal sleeve was added to prevent disintegration of the linen-Micarta flare casing. It increased the unit weight to 1.67 pounds. The added result is an increase in the radiant intensity in the 1.5µm to 2.7µm bandpass region with a decrease in burning time at altitude.

**TAU-15 107E Flare:** Ordnance Research Inc provided this unit in the form of a cast pyrotechnic flare to simulate the TAU-15 flare system. The units are in the form of a 6-inch long by 1.250-inch outside diameter cylinder containing a castable magnesium-fluorocarbon composition.

**TAU-50 Flare and TAU-56/B Flare:** See the comment in the description of the AGX0827 target flare about erroneous identification.

**TAU-56/B Target Flare-Earlier Variant:** Aerojet-General built this flare about 1963. It has an outer case diameter of 2.0 inches. The length of the outer steel shell is 12.5 inches. The flare composition weight is 1.5 pounds. The total device weight is 3.5 pounds. The nominal burning time is 90 seconds.

**TAU-56/B Target Flare-Later Variant:** A later variant built by Aerojet-General, which was put into production, had a nickel-plated steel outer casing diameter of 2.5 inches giving the flare composition 70% more burning area than the earlier variant. The overall flare length including the ogive nose is 15.1 inches. The unit weighs 4.7 pounds. This flare is intended for use on the Q-2C drone and the TDU-9/B tow target. The composition, in parts by weight, is 65 parts magnesium powder, 35 parts Teflon®, and 5 parts anthracene. Flares made after July 1963 contain 3 or 4 parts by weight anthracene.

**TAU-56 105E Flare:** Ordnance Research Inc provided this pyrotechnic cast flare to simulate the TAU-56 flare system. The units are in the form of a 6-inch long by 1.250- inch outside diameter cylinder containing a castable magnesium-fluorocarbon composition. The composition is similar to that in the W251 flare.

**Tactical Fighter Attack Flare (TFAF):** A model of the TFAF flare, about 3.1 inches long by 0.4 inches in diameter with four fins on the tail was used at the Arnold

Engineering Development Center, Arnold Air Force Station Tennessee to determine safe separation of the flare from an F-4C aircraft.

**XADR-9 Countermeasure Flare:** The XADR-9 forward launched countermeasure flare is the payload for the XADR-9A countermeasure rocket system. The Flare Northern Division of the Atlantic Research Corporation developed the flare for Tracor Inc., the prime contractor for the XADR-9 rocket. The payload also is identified as the RR-96 flare. The ADR-9A countermeasure rocket system is compatible with the AN/ALE-25 pod mounted dispenser on B52-H aircraft. The unit, including the chaff dispenser system, the flare and the rocket propulsion system is 74 inches long by 2.75 inches in diameter. The flare grain composition, in parts by weight, is 39.1 parts 1H,1H,7H dodecafluoro-1-heptylmethacrylate, 47 parts magnesium, 1 part bis-phenyl-A-dimethylacrylate, 2 parts aluminum staples, and 4 parts anthracene. The grain is 16 inches long by 2.125 inches in diameter and weighs 5.2 pounds. This flare is unique in configuration, consisting of an internal-burning cast grain with a six-gear tooth axial channel. The internal burning performance provides the infrared signal without weakening the walls of the entire structure during the 12-second life of the countermeasure system.

**RITA and FLORA Flares:** The so-called RITA and FLORA flares make up a family of flares developed by Picatinny Arsenal for the Air Force for protection of the B-52 bomber. Their contents evolved from an illuminating composition for visible output to a composition that radiates in the infrared. The RITA-FLORA developmental evolutions lead to the development of the ALA-17 MTV flare.

**RITA Flare:** The generic RITA flare has a composition for light production that is 66.7% magnesium, 28.5% sodium nitrate, and 4.8% binder.

**RITA Flare 3-second variant:** The RITA flare 3-second variant is 1.75 inches in diameter by 1.75 inches long. The illuminating composition consists of 47.6% magnesium (22µm particle size), 47.6% sodium nitrate and 4.8% Laminac® binder. Picatinny Arsenal fabricated this flare. Mentioned in 1956 report.

**RITA Flare 5-second variant:** The RITA flare 5-second variant is 1.75 inches in diameter by 1.75 inches long. The illuminating composition consists of 23.8% magnesium (gran 17), 23.8% magnesium (22µm particle size), 47.6% sodium nitrate and 4.8% Laminac® binder. Picatinny Arsenal fabricated this flare. Mentioned in 1956 report.

**RITA Flare Jacketed variant:** The RITA flare jacketed variant is fabricated with the same formulation and dimensions as the 5-second variant RITA flare. It is pressed into a steel wire mesh screen in the form of a cylindrical sleeve extending over the complete wall area. Both ends of the flare are uncovered. The overall length is 2-inches. Picatinny Arsenal fabricated this flare. Mentioned in 1956 report. This design may be related to the perforated-can flare design.

**RITA-I Flare:** The RITA-I flare is 1.875 inches in diameter by 5.75 inches long. It contains a composition of 54% magnesium, 44% Teflon® and 2% nitrocellulose. The flare burns on all surfaces for 11 seconds at ground level. Picatinny Arsenal developed the RITA-1 flare.

**RITA-II Flare:** The RITA-II flare is 2.25 inches in diameter by 5.75 inches long. It is identical to the RR-98/ALE Decoy Flare except in size. It contains a composition of 54% magnesium, 44% Teflon® and 2% nitrocellulose. The flare burns on all surfaces for 6 seconds at ground level. The RITA-II flare was developed for the AN/ALE-14 dispenser and the AN/ALE-20 dispenser systems for B-47 and B-52 bombers respectively. Picatinny Arsenal developed the RITA-II flare. The RITA-II flare is regarded as the precursor of the ALA-17 flare.

**RITA-III Flare:** The RITA-III flare is 2.59 inches in diameter by 2.1 inches long. It contains an infrared composition of 70% magnesium and 30% Teflon®. Another reference gives the dimensions as 5 inches long by 1.750-inches in diameter. Picatinny Arsenal developed the RITA-III flare.

**FLORA Flare:** The FLORA flare started with a RITA flare that initially contained 66.7% magnesium, 28.5% sodium nitrate and 4.8% binder composition. That composition radiates in the visible. Later it was loaded with a mixture of 54% 22- $\mu$ m mesh magnesium and 46% Teflon®-7X to provide infrared radiation. The FLORA flare grain is cylindrical, weighs about 1545 grams, and occupies 54.75 cubic inches. The grain has an 80.22 square inch surface area. Burning takes place simultaneously over the entire surface.

**FLORA Type B Flare:** The composition in the FLORA Type B flare consists of 42% magnesium, 49.2% Teflon® and 8.8% of a boron-barium chromate mixture. The latter mixture consists of 16% boron and 84% barium chromate. The FLORA Type B flare grain is cylindrical, weighs about 1545 grams, and occupies 54.75 cubic inches. The grain has an 80.22 square inch surface area. Burning takes place simultaneously over the entire surface.

**FLORA Type C Flare:** The composition in the FLORA Type C flare consists of 39.9% magnesium, 46.8% Teflon® and of a 13.3% boron-barium chromate mixture. The latter mixture consists of 16% boron and 84% barium chromate. The FLORA Type C flare grain is cylindrical, weighs about 1545 grams, and occupies 54.75 cubic inches. The grain has an 80.22 square inch surface area. Burning takes place simultaneously over the entire surface.

## Flares Assigned a Mk and Mod

**Mk 3 Mod 0 Target Flare:** The Mk 3 Mod 0 target flare is also known as the BB-9 flare. It has a burning time of 30 seconds. The manufacturer is the Hughes Aircraft Company. It is electrically ignited with dimensions of 2.25 inches in diameter by a little over 8 inches long. The BB-9 has a very high airborne output that varies considerably during burning.

**Mk 21 Mod 0 Tracking Flare** The illuminating composition in the Mk 21 Mod 0 tracking flare is 54% magnesium, 34% sodium nitrate, and 12% Laminac®, a polyester binder. It is packaged in the Mk 26 Mod 0 target rocket kit. This tracking flare is intended to ignite parasitically from thrust gases of the propulsion unit in environments up to Mach 1.5 and acceleration forces up to 80 G's. The burning duration is 15 seconds at an intensity of 100,000 candela (visible) and about 50 W/sr in the infrared. The 1-inch diameter by 10 inches long case is aluminum. It has marginal ignition above 35,000 feet altitude. The developmental precursor of the Mk 21 Mod 0 flare is the NOTS Model 701A.

**Mk 23 Mod 0 Guided Missile Flare:** The Mk 23 Mod 0 guided missile flare is also known as an electric tracking flare for the Bullpup missile. Its purpose is to permit tracking of missile trajectories. It is 10 inches long by 1.75 inches in diameter and contains about 0.28 pounds (126 grams) of pyrotechnic components. The NOTS Model 714A flare replaced the Mk 23 Mod 0 flare.

**Mk 25 Mod 0 Tracking Flare:** The Mk 25 Mod 0 flare is used to track the Talos missile. It has a 0.125-inch thick cotton-based phenolic body.

**Mk 26 Mod 0 Target Rocket Kit:** The Mk 26 Mod 0 kit contains the Mk 21 Mod 0 tracking flare.

**Mk 27 Mod 0 Guided Missile Flare:** The Mk 27 Mod 0 flare underwent Prototype Production for Evaluation at NAD Crane in the early 1960s. It evolved from the NOTS Model 714A tracking flare for the Bullpup missile. This version burns about 40 seconds with visible intensity of 100,000 candela in the first 2-8 seconds and 140,000 candela thereafter.

**Mk 28 Mod 0 Tracking Flare:** The Mk 28 Mod 0 flare evolved from the NOTS Model 711A flare alternatively known by the Air Force as the TAU-15/B flare. The infrared grain composition in the Mk 28 Mod 0 flare consists of 54% magnesium, 30% Teflon® and 16 % Kel-F® #40 wax to which 3 to 5 parts by weight of graphite is added to facilitate consolidation of the composition. The grain is 1.44 inches in diameter by 9.5 inches long. The flare is used to track tow targets.

**Mk 28 Mod 1 Tracking Flare:** The infrared grain composition in the Mk 28 Mod 1 flare consists of 54% magnesium, 30% Teflon® and 16 % Kel-F® wax to which 3

parts by weight graphite is added to facilitate consolidation of the composition. The ignition composition is a mixture of 90% barium chromate and 10% boron powder.

**Mk 28 Mod 2 Tracking Flare:** The Mk 28 Mod 2 flare evolved from the Mk 28 Mod 1 tracking flare. The Mk 28 Mod 2 flare also uses Kel-F® wax as a binder. Because there were problems with the Kel-F® wax, a new formula was developed. The flare with the new formula with Viton® A became the Mk 28 Mod 3 Tracking Flare.

**Mk 28 Mod 3 Tracking Flare:** The Mk 28 Mod 3 flare evolved from the Mk 28 Mod 2 tracking flare. It is used as a target for infrared seeking missiles. It burns for about 48 seconds when deployed at 40,000 feet at 0.7 Mach. The infrared composition in the grain of the Mk 28 Mod 3 flare is 60 parts magnesium powder, 40 parts Teflon® and 5 parts Viton® A by weight. The ignition composition is a mixture of 90% barium chromate and 10% boron powder. In 1963, Mr. Leonard B. Arnold conducted the Prototype Production for Evaluation (PPE) of this flare at NAD Crane. The favorable performance during PPE qualified the unit for release to production.

**Mk 33 Mod 0 Tracking Flare:** The Mk 33 Mod 0 flare was designed for visually tracking the Sidewinder 1A and 1C missiles. It also is added to Mk 26 Mod 0 target rocket kits where it is used for Sidewinder 1A target augmentation. The forerunner of the Mk 33 Mod 0 flare is the NOTS Model 702B flare. The Mk 33 Mod 0 flare is 1-inch in diameter by 10 inches long. The grain composition contains 54% magnesium gran 15, 30% Teflon® no. 1, and 16% Kel-F® wax no. 40. Whereas the grain composition formula is typical of an infrared composition, one should not overlook that the burning composition also radiates a large amount of light. Ignition problems were noted during tests due to slipstream damage to the flares. NOTS forwarded the Mk 33 Mod 0 flare documentation package to the Navy Headquarters on 19 January 1962.

**Mk 33 Mod 1 Tracking Flare:** To overcome the Mk 33 Mod 0 flare ignition problems, 8-evenly spaced 0.1875-inch holes replaced the parasitic slots to insure positive ignition of the Mk 33 Mod 1 flare. This resulted in assignment of Mk 33 Mod 1 tracking flare as the new designation replacing the Mk 33 Mod 0 flare. Burning takes place simultaneously over the entire surface. The grain of the MK 33 Mod 1 tracking flare consists of 54% magnesium gran 16, 30% Teflon® no. 1, and 16% Viton® A. This is a NOTS development.

**Mk 37 Mod 0 Infrared Target Flare:** The Mk 37 Mod 0 is the target flare developed by Special Devices, Incorporated for the Teledyne Ryan BQM-34 drone, one of the first jet-propelled targets, which later became known as the Firebee. Two flares are carried on each wing tip and are ignited individually on command. The Mk 37 Mod 0 flare is 21.6 inches long by 3 inches in diameter. The grain is prepared by an incremental pressing technique. The grain composition consists, in parts by weight, of 46.5 parts magnesium, 13.6 parts aluminum, 38.1 parts Teflon® and 1.8 parts Vistanex™ solids. The ignition composition consists of a mixture of 10% boron and

90% barium chromate. The first fire consists of a mixture of magnesium, Teflon®, boron, polyisobutylene and barium chromate. Earlier, Special Devices Incorporated developed the 5B1.5.1-1 flare, the forerunner of the Mk 37 Mod 0 flare. The Special Devices 5B1.5.1-1 infrared flare and the Mk 37 Mod 0 flare later were both found to be unsatisfactory. The Targets Office at the Naval Missile Center, Point Mugu, California reported ignition failures with the Mk 37 Mod 0 flare, and also that it burned holes in the motor when tested at 3,000 feet altitude on the Beech AQM-37A small supersonic air-launched expendable target drone. In September 1963, the KD2B-1 drone production version became operational with the U. S. Navy. Shortly before, in June 1963, the KD2B-1 drone was redesignated as the AQM-37A drone.

**EX 42 Mod 0 Decoy Flare:** This flare was developed for use in Lundy AN/ALE-33 chaff dispensers. The EX 42 Mod 0 flare and the EX 43 Mod 0 flare are similar in that they essentially are flat slabs of grain material expelled from dispensers at a comparatively low velocity. The pyrotechnic pellet is in the shape of a rectangular block, which is totally encased in a plastic outer cover. It is about 4.9 inches long by 2.90 inches wide by 0.875 inches thick. There are about 0.43 pounds (196 grams) of energetic materials in this device.

**Mk 42 Mod 0 Decoy Flare:** This flare was developed for Lundy chaff/flare dispensers. It is derived from the NOTS Model 733 series flare. The flare format, similar to the RR-72 flare cartridge, is extruded in a rectilinear shape 4.875 inches long by 3 inches wide by 1.031 inches thick. Specifications include a release velocity of Mach 0.9, a functioning range of up to 70,000 feet altitude and a burning time of at least 2 seconds at 50,000 feet. The Mk 42 Mod 0 flare was adapted to the Lundy AN/ALE-33 chaff dispenser.

**EX 43 Mod 0 Decoy Flare:** This flare was developed for use in AN/ALE-18 chaff dispensers. The EX 42 Mod 0 flare and the EX 43 Mod 0 flare are similar in that they essentially are flat slabs of grain material expelled from dispensers at a comparatively low velocity. The wedge-shaped pyrotechnic pellet is totally encased in a plastic outer cover. There are about 0.54 pounds (243 grams) of energetic materials in this device.

**MK 43 Mod 0 Decoy Flare:** This flare is derived from the NOTS Model 715 flare. It is an extruded wedge configuration with 24 units fitting into the AN/ALE-18 pneumatic chaff dispenser. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A. The grain shape is 3.6 inches wide by 2.73 inches long by 1.06 inches thick. The thickness dimension tapers to 0.34 inches.

**EX 46 Mod 0 Decoy Flare:** As reported by Dr. Handler and Mr. J. W. Hanzel of China Lake in 1967, they started work on the development of the EX 46 Mod 0 flare in June 1966. The predecessor to the EX 46 Mod 0 flare is the NOTS Model 400A decoy flare. The NOTS Model 400A flare's composition consists of 55% magnesium, 30% Teflon®, and 15% Viton® A. Pyrotechnicians at NOTS were

requested to develop this flare as a backup to a similar flare being developed by Unidynamics/Phoenix Division Arizona. Ignition is by a pull wire igniter. The ignition strip is made from composition PL 6239. The original grain consists of composition PL 6239. Based on flight test information, the grain composition was changed from composition PL 6239 to composition PL 6328 to obtain a shorter rise time and greater average output. During a second flight test, they evaluated composition PL 6920, a very high-output short-burning composition. Initial performance data were favorable. The device weight is about 0.53 pounds (240 grams). The diameter is 1.4 inches and the overall length is 5.875 inches. The EX 46 Mod 0 decoy flare was developed for the AN/ALE-29 chaff dispenser. That dispenser requires a cylindrical package to be expelled at a relatively high velocity. The design for the EX 46 Mod 0 decoy flare was frozen in December 1966.

**Mk 46 Mod 0 Decoy Flare:** NOTS investigators reported that work started in mid-1966 on the development of the EX 46 Mod 0 decoy flare, which evolved into the Mk 46 Mod 0 decoy flare. The design is derived from the NOTS Model 400A flare. The Mk 46 Mod 0 decoy flare was released to limited production in December 1967. Its purpose is to protect A-3, A-4, A-6, A-7, F-4 and F-8 aircraft against the AA-2 Atoll air-to-air missile threat. These aircraft have the AN/ALE-29 chaff-flare dispenser installed.

The flare is 1.43 inches in diameter by 5.81 inches long and has a flare grain weight of 0.36 pounds (165 grams). The MTV formulation selected for the grain is composition PL 6239. The Mk 46 Mod 0 flare is initiated with a pull wire igniter and has a cross hole through the grain near the center. The ignition process propagates by the flame from the pull wire through the cross hole to ignite the ribbon of igniter material, which in turn ignites the grain. The grain is made by the extrusion process. The flare has a longitudinal flat spot extruded on the circumference of the grain. A ribbon of igniter material is stapled onto the flat spot. In this configuration, the grain is assembled into the case. The grain is not wrapped with aluminum foil tape. The inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process.

The Air Test and Evaluation Squadron Four (VX-4) at Point Mugu California evaluated the Mk 46 Mod 0 flares for effectiveness. VX-4 used the Sidewinder AIM-9B missile as a surrogate for the Atoll threat missile. The device is compatible with the AN/ALE-29A dispenser, the AN/ALE-37A dispenser, and the AN/ALE-39 dispenser. Dr. Handler of China Lake reports that the Mk 46 Mod 0 flare replaced the Mk 47 Mod 0 flare and that the Mk 46 Mod 0 flare does not have a fast enough rise to peak intensity to protect against advanced missiles. This is a NOTS development. NAD Crane manufactured the flare.

**Mk 46 Mod 1 Decoy Flare:** The improved version of the Mk 46 Mod 0 flare became the Mk 46 Mod 1 flare. It was improved for high altitude use and had a faster rise

time to peak intensity. The flare is 1.43 inches in diameter by 5.81 inches long. The Mk 46 Mod 1 flare is initiated with a pull wire igniter and has a cross hole through the grain near the center. The ignition process propagates by the flame from the pull wire igniter through the cross hole to ignite the ribbon of igniter material, which in turn ignites the grain. The grain is made by the extrusion process. The flare has a longitudinal flat spot extruded on the circumference of the grain. A ribbon of igniter material is stapled onto the flat spot. In this configuration, the grain is assembled into the case. The grain is not wrapped with aluminum foil tape. The inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process. NOTS developed this improvement. NAD Crane manufactured the flare.

**Mk 46 Mod 1A Decoy Flare:** This Navy MTV flare is 1.43 inches diameter by 5.81 inches long. The flare is initiated with a pull wire igniter and has a cross hole through the grain near the center. The ignition process propagates by the flame from the pull wire igniter through the cross hole to ignite the ignition slurry, which in turn ignites the grain. The grain is made by the extrusion process. There are 10 longitudinal grooves extruded onto the grain circumference, which are filled with ignition slurry. The grain in this flare is wrapped with aluminum foil tape. For the Mk 46 Mod 1A, the inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process. The Mk 46 Mod 1A flare has a multi-piece cartridge retainer assembled inside the case at the ignition end. Mentioned in a 1977 report.

**Mk 46 Mod 1B Decoy Flare:** The MTV composition formulation in this variant was modified to provide faster burning, which in turn results in a much higher radiant intensity. The grain has 12 longitudinal grooves on the grain surface, maybe the first to incorporate such a design. The 12 grooves in comparison to the 10 grooves of the MK 46 Mod 1C flare provided extra burning surface. The grooves are filled with ignition slurry. The grooves are formed during the extrusion process. The grain in this flare is wrapped with aluminum foil tape. Other design features are similar to those in the Mk 46 Mod 1A flare. The Mk 46 Mod 1B flare later was redesignated the MJU-8/B decoy flare. This flare is 1.43 inches diameter by 5.81 inches long.

**Mk 46 Mod 1C Decoy Flare:** This Navy MTV flare is 1.43 inches diameter by 5.81 inches long. The flare is initiated with a pull wire igniter and has a cross hole through the grain near the center. The ignition process propagates by the flame from the pull wire igniter through the cross hole to ignite the ignition slurry, which in turn ignites the grain. The grain is made by the extrusion process. There are 10 longitudinal grooves extruded onto the grain circumference, which are filled with ignition slurry. The grain in this flare is wrapped with aluminum foil tape. For the Mk 46 Mod 1C, the inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition

end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process. The Mk 46 Mod 1C flare has a one-piece cartridge retainer assembled inside the case at the ignition end, which is an improvement over the multi-piece cartridge retainer in the Mk 46 Mod 1A.

**Mk 47 Mod 0 Decoy Flare:** The MK 47 Mod 0 flare was developed and manufactured by Unidynamics Division of Universal Match Corporation Industries. This flare is described in specification MIL-F-81545 Flare, Decoy. It is 1.43 inches in diameter by 5.81 inches long with a flare grain weight of 0.23 pounds (105 grams). The composition is pressed to make the grain. This flare was actually the first decoy flare designed for use in the AN/ALE-29 dispenser. It entered production in 1968. After the Illinois Institute of Technology Research Institute developed inertial bore-safe igniter parts and the grain are ejected, the safing hardware ignites the grain at the rear. The AN/ALE-29A dispenser has 30 tubes into which the flares are loaded. Dr. Handler of China Lake reports that the Mk 46 Mod 0 flare replaced the Mk 47 Mod 0 flare.

**Mk 48 Mod 0 Decoy Flare:** This is a NWC China Lake developed flare intended for ship protection. It is also known as the Ships Ordnance Infrared Decoy (SOID). In July 1968, China Lake was requested to develop this flare when it appeared the Army 33-18 flare development would not be available on schedule. The decoy grain is a magnesium/Teflon®/Viton® A rod extruded 1 inch in diameter by 12 inches long. The grain composition consists of a variation of composition PL 6328. This grain is assembled into a Mk 25 Marine Marker aluminum canister, which is about 18 inches long by 3 inches in diameter. The Mk 48 Mod 0 flare is initiated by the introduction of seawater to the interior of the base assembly. The ignition system consists of a Mk 72 seawater activated battery, which is mounted within the base assembly, and a Mk 1 squib fitted in the forward end of the flare grain. It was released to production in 1971. The Mk 48 Mod 0 flare can only be launched by hand. NAD Crane manufactured the flare.

**Mk 48 Mod 1 Decoy Flare:** The Mk 48 Mod 1 decoy flare is similar to the Mk 48 Mod 0 flare. It differs in that it can be launched either by hand or from the Mk 133 Mod 0 flare launcher system.

**EX-49 Mod 0 Decoy Flare:** This is the forerunner of the Mk 49 Mod 0 flare. The grain burns internally and externally. Initially the grain had a twelve-star shaped perforation longitudinally in the grain center. In early 1971, the design with 12-longitudinal holes around the circumference was chosen in place of the star shaped perforation. The 12-hole configuration was designated the EX 49 Mod 0 flare. Mentioned in a 1971 report. Developed by NWC, China Lake.

**Mk 49 Mod 0 Decoy Flare:** This flare has a new bore safe system and is 1.42 inches in diameter by 5.80 inches long. The grain is 1.33 inches in diameter by 4.87 inches long. The flare grain weighs 0.34 pounds. The flare mixture is composition PL 9000. The Mk 49 Mod 0 decoy flare was first mentioned in a June 1973 report.

Mr. Daniel L. Harp, Mr. Kenneth L. Foote, and Mr. Allen of China Lake reported details of this flare in early 1974. This flare is also known as the "spaghetti" flare. The grain has twelve 0.125-inch longitudinal holes around the circumference of the grain very close to the outside perimeter. An extruded ignition cord composed of magnesium-Teflon® composition PL 6239 mixture, called spaghetti, is lased continuously through all the holes. This Mk 49 Mod 0 flare design is a successor to the Mk 46 Mod 0 flare and is the forerunner to the MJU-8A/B decoy flare by way of the MJU-16/B flare, the MJU-21(XCA-1)/B flare and the MJU-8/B PIP flare. Sometimes graphite is added to the composition to improve the grain extrusion properties. Graphite also is supposed to improve the burning rate and long wavelength properties. Naphthalene and anthracene also were explored to improve long wavelength properties. A spaghetti flare grain is configured such that the extrusion process is the only way to produce it. The Mk 49 Mod 0 was not released to production.

**EX 50 Mod 0 Decoy Flare:** This MTV flare is about 1972 vintage and is the forerunner to the Mk 50 Mod 0 flare. The case features are 1.57 inches in diameter by 3.85 inches long with a weight of 0.43 pounds. The grain features are 1.4 inches in diameter by 2.4 inches long with a weight of 0.22 pounds. The EX 50 Mod 0 pyrotechnic grain is N-35 propellant. The EX 50 Mod 0 has a much faster burning rate than the Mk 50 Mod 0 flare.

**Mk 50 Mod 0 Decoy Flare:** This flare is a quick response development designed to be compatible with the AN-M8 pyrotechnic pistol, from which the decoy flare is fired. The unit consists of a 1.57-inch diameter by 3.85-inch long aluminum case that has a rimmed base to fit the pistol ejector. The extruded MTV grain is 1.4 inches in diameter by 2.4 inches long. It contains approximately 0.22 pounds (100 grams) of flare grain, which is coated internally on each end with 0.70 grams of ignition charge mixture. The propelling charge is 2.5 grams black powder. An M39A1 percussion primer is located in the base end. The Mk 50 Mod 0 decoy flare is identical to the EX 50 Mod 0 flare, with one minor exception. The magnesium powder used in the Mk 50 Mod 0 flare could not meet the specification for use in N-35 propellant. Mk 50 Mod 0 flare grains are extruded from composition PL 9001, which is similar to N-35 in formulation but allows the use of a wider magnesium particle size range. Development of the Mk 50 Mod 0 decoy flare by NWC China Lake was completed in 1972. Unlimited production was authorized in 1973. The Naval Ordnance Station Indian Head Maryland produced this flare. The MTV Army XM-197 flare is similar to the Mk 50 Mod 0 flare.

**EX 51 Mod 0 Decoy Flare:** The EX 51 Mod 0 flare development, started in 1972. It is an effort to get increased infrared radiant intensity for greater effectiveness and wider use knowing that the Mk 50 Mod 0 is deficient in that regard. The grain in the Mk 50 Mod 0 flare is made of N-35 propellant, which is intended primarily for use as a propellant and gives less infrared emission than those formulations intended for pyrotechnic use. It also is limited in combustion at high altitude. The intent is to replace the N-35 propellant in the Mk 50 Mod 0 flare with a composition that has a

greater infrared output and better functioning at altitude. The replacement formulation is composition PL 9000, which is composition PL 6920; 70% magnesium, 14% Teflon® and 16% Viton® A, with 10% graphite added. The composition ignites reliably with CT-144 ignition mix. The EX 51 Mod 0 flare is designed to be compatible with the AN-M8 pyrotechnic pistol, which is used to launch this decoy flare. The development was put on hold awaiting a request from Navy Headquarters that the item be produced or for an operational requirement. There is no record that the hold was removed from this development.

## Flares Assigned an MJU Designation

**MJU-2/B Aircraft Decoy Flare:** NAD Crane engineers developed the MJU-2/B flare. The flare is 7.625 long by 1.568 inches in diameter. It contains 0.47 pounds (215 grams) of MTV composition and is ejected at 40 feet/second. The grain exterior is grooved to get additional surface area. Magnesium-Teflon® tubing is placed into the grooves to provide high initial radiant output. The flare exhibits a 300-millisecond rise time and a 3.2 second ambient burning time. At 40,000 feet altitude and 650 feet per second airspeed, it burns about 4.5 seconds. The flare is dispensed from the A6 or 9A Lambert photoflash ejector or a SUU-53A cartridge dispenser. The latter dispenser typically is used to discharge Weather Modification Units (WMU) catalyst generators units. WMU units are used for cloud seeding in an effort to facilitate rainmaking. Mr. Harold L. Benham and Mr. Orville L. Beckes NAD Crane reported this flare in 1974.

**MJU-2A/B Aircraft Decoy Flare:** This flare is an improved version of the MJU-2/B flare. The improvement is mainly in the ignition system. The extruded MTV grain exterior is grooved to get additional surface area. This flare dates to 1988.

**MJU-3/B Countermeasures Flare:** This flare and its dispenser are too large except for logistics aircraft. The flare also needs a reduced delay time. Mentioned in a 1972 report.

**MJU-7/B Aircraft Decoy Flare:** Prior to 1989 there only was one flare called the MJU-7/B flare, but it had 2 variants, which are not distinguished by a change in nomenclature. All variants are made with MTV to the same performance specification. The flare dimensions are 1 inch by 2 inches by 8 inches. The MJU-7/B flares are compatible with the Tracor AN/ALE 40 dispenser.

**MJU-7/B Aircraft Decoy Flare variant 1:** Before 1997, this variant of the MJU-7B flare was made with a pressed MTV grain and with a slider/interrupter/sequencer. The flare dimensions are 1 inch by 2 inches by 8 inches.

**MJU-7/B Aircraft Decoy Flare variant 2:** Before 1989, this variant of the MJU-7/B flare was made with an extruded MTV grain and was ignited parasitically. It does not have a slider/interrupter/sequencer. The flare dimensions are 1 inch by 2 inches by 8 inches.

**MJU-7A/B Aircraft Decoy Flare:** Starting in 1997 the Air Force had some flares made with an extruded MTV grain as in the MJU-7/B variant 2 flare and with a slider/interrupter/sequencer as in the MJU-7/B variant 1 flare. The designation given to these flares with an extruded MTV grain and with a slider/interrupter/sequencer is the MJU-7A/B flare. At this time, the manufacturing specification for the MJU-7A/B flare was changed to give the producer the option to choose which version (pressed or extruded grain) to make. The performance requirements stayed the same for the MJU-7A/B flare whether the grain is made by pressing or by extrusion. There was

no effort to change the nomenclature to indicate whether the flare contained a pressed grain or an extruded grain. This later made it difficult to identify the type of grain contained in an MJU-7A/B flare. The flare dimensions are 1 inch by 2 inches by 8 inches.

**MJU-8/B Aircraft Decoy Flare:** The MJU-8/B flare is formulated using extruded MTV to protect aircraft that radiate a large infrared signature. It is the counterpart to the Mk 46 Mods flare series that are formulated to protect aircraft that radiate a low infrared signature. The MTV composition formulation and grain configuration in this variant were modified to provide faster burning, which in turn results in a much higher radiant intensity. The grain has 12 longitudinal grooves on the grain surface, maybe the first to incorporate such a design. The 12 grooves in comparison to the 10 grooves of the MK 46 Mod 1C flare provided extra burning surface. The grooves are formed during the extrusion process. The grooves are filled with ignition slurry. The grain in this flare is wrapped with aluminum foil tape. Other design features are similar to those in the Mk 46 Mod 1C flare. The Mk 46 Mod 1B was redesignated the MJU-8/B decoy flare. This flare is 1.43 inches diameter by 5.81 inches long.

**MJU-8/B PIP Aircraft Decoy Flare:** This MTV extruded flare evolved into the MJU-8A/B decoy flare and is 1.43 inches in diameter by 5.81 inches long. The forerunner of this flare is the MJU-21(XCA-1)/B flare. The concept of longitudinal holes and the spaghetti igniter material continues in this variant.

**MJU-8A/B Aircraft Decoy Flare:** The forerunner of this MTV extruded flare is the MJU-8/B PIP. The MJU-8A/B flare is 1.43 inches in diameter by 5.81 inches long. This flare also utilizes the "spaghetti" flare design. The grain has twelve 0.125-inch longitudinal holes around the circumference of the grain very close to the outside perimeter. An extruded ignition cord composed of magnesium-Teflon® PL 6239 mixture, called spaghetti, is laced continuously through all the holes. This variant dates from 1986.

**MJU-10/B Aircraft Decoy Flare:** The MJU-10/B flare is a 2 inch by 2.5 inch by 8 inch MTV decoy flare primarily used on an Air Force aircraft.

**MJU-16/B Aircraft Decoy Flare:** The MJU-16/B flare is 1.43 inches in diameter by 5.81 inches long. It served as the test bed for a number of improvement concepts. This MTV flare also has the longitudinal holes around the grain circumference very near to the surface. It is into these holes that the spaghetti igniter material is laced. This design never was placed into production. The MJU-16/B flare improvements evolved into the MJU-21(XCA-1)/B flare.

**MJU-21(XCA-1) Aircraft Decoy Flare:** This MTV extruded flare is 1.43 inches in diameter by 5.81 inches long. It evolved from MJU-16/B flare developments into the MJU-8/B PIP decoy flare. The MJU-21(XCA-1) flare continued the spaghetti flare concept but in this instance, the longitudinal holes are relieved to the outside by a

small slot. This is done to regulate the ignition rate. Igniter material in the form of spaghetti is laced into these holes as in prior models. This variant dates to 1985.

**MJU-22/B Aircraft Decoy Flare:** This MTV extruded flare is 1.43 inches in diameter by 10.55 inches long. It might be considered the “long” version of the MJU-8A/B flare. It also contains the spaghetti flare concept and associated design. The extra length design allows one to dispense a flare with more radiative output from a single hole of the dispenser. This variant dates from 1991.

**MJU-32/B Aircraft Decoy Flare:** This MTV extruded flare is an improvement of the MJU-8A/B flare. It also is 1.43 inches in diameter by 5.81 inches long. The lacing of the spaghetti into the longitudinal holes of the grain is a very labor-intensive procedure. To reduce the labor cost, the holes were changed into a “T” shaped slot. Spaghetti no longer is required in this design. The concept of the “T” slot is that it would undergo fissure burning and there would no longer be a need for an igniter material in the slot. After many experiments with the shape of the slot, the final “T” shaped slot was chosen as the optimum balance between ignition speed and performance. Mr. Jeff Mulinix of NSWCR Crane is the inventor of the “T” slot. This flare dates from 1995.



## Flares with Commercial Designations

**E216 Tracking Flare (Ejectable):** This is a double-end burning ejected flare made by the Atlantic Research Corporation. The E216 flare is identical to the W216 flare. The MTV grain is 1.625 inches in diameter by 3 inches long and weighs 0.22 pounds. The composition is EW-50. The materials and proportions are unspecified.

**W111B Tracking Flare:** This is a commercial item made by the US Flare Corporation (USFC). It is 1 inch in diameter by about 10.125 inches long. It is electrically ignited and weighs about 0.75 pounds. The USFC W111B flare is interchangeable with the NOTS Model 702A flare.

**W112B Infrared Augmentation Device:** This device is for the modified 5-inch HVAR rocket powered TDU-11B target. It was designed to replace the Mk 21 Mod 0 flare. The first article was tested during 1963 at the Air Proving Ground Center, Eglin Air Force Base Florida to get data about performance at sea level and 22,000 feet altitude. The burning time at altitude is 70 seconds at 240 knots indicated air speed (KIAS). The flare is reliable over the minus 65 °C to +30 °C temperature regime. US Flare Division of the Atlantic Research Corporation manufactured the flare. The composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® wax. The grain is pressed in increments into an aluminum case, which is thin walled and is consumed during burning. Since it is mounted on the target, the case burns in place and is not ejected. The front end has the ignition mixture exposed through vents to facilitate parasitic ignition by the rocket flame. The aluminum case is 6.5 inches long by 0.94 inches in diameter. The unit weighs about 0.5 pounds.

**W114B Tracking Flare:** This commercial flare is intended for use on the AGM-45A Shrike missile to obtain missile trajectory. Because of problems with this unit, the NOTS Model 743A flare and NOTS Model 743B flare were tried instead of the W114B flare.

**W137 Tracking Flare:** This flare was developed by US Flare Division of the Atlantic Research Corporation and was designed primarily for use with the Pogo-Hi rocket. The unit is 1.375 inches in diameter by 9 inches long and weighs about 1 pound. The grain weighs about 0.33 pounds. The unit burns for 40 seconds at sea level with an intensity of 450 W/sr in the 1.8µm to 2.7µm bandpass region. The W137 flare is ignited with one USF Model 706 Squib. The actual burning time is 120 seconds when mounted on the Pogo-Hi rocket during the time it is rising from ground launch to 68,000 feet and then free-falling back to the ground. The W137 flare is one of the earliest magnesium-Teflon® formulated flares. It dates to before October 1959.

**W138 Tracking Flare:** This flare is identical to the W137 flare but burns for 20 seconds at sea level and for 60 seconds in flight.

**W204 Infrared Flare:** US Flare Division of the Atlantic Research Corporation made the flare, which is in a 2-inch diameter by 10-inch long case. The W204 flare and the W205 flare differ in case material.

**W205 Infrared Flare:** US Flare Division of the Atlantic Research Corporation made the flare, which is in a 2-inch diameter by 10-inch long case. The W204 flare and the W205 flare differ in case material.

**W205 Lot 1 Target Flare:** This flare, manufactured by the Atlantic Research Corporation, is used on the TDU-4/B Tow Target. The flare is not ejected, but burns where it is mounted. An electrical connector at the rear end is used to ignite an electric agent embedded in the first fire at the front end. Ignition is by electric squib. The grain is in a stepped aluminum case that is wider at the front end. A layer of fiberglass insulation separates the grain and the aluminum in the wider position of the tube. The grain is in a 2-inch diameter case stepped down to 1.75 inches in diameter by 9.5-inch long case. The device weighs 2.05 pounds. The grain inside the case is 1.56 inches in diameter by 7.5 inches long. The grain composition consists of 57% magnesium, 38% Teflon®, 2% Shell Epon 864 epoxy binder, and 3% phenanthrene.

**W205 Lot 2 Target Flare:** Flare-Northern, formerly US Flare Corporation, built this target flare that is 2.0 inches in diameter and has an overall length of 10.25 inches. It is necked down to 1.75 inches in the area between 6.125 and 6.375 inches from the burning end. It contains a flare pellet approximately 1.5 inches in diameter by 8.5 inches long. The grain composition is approximately 65 parts by weight magnesium powder, 35 parts Teflon®, and 5 parts anthracene. The burning time is about 90 seconds. Flares made after July 1963 contain 3 or 4 parts by weight anthracene. Besides the manufacturer, the difference between the W205 Lot 1 flare and the W205 Lot 2 flare is mainly in the infrared composition; the configuration being quite similar.

US Flare Division of the Atlantic Research Corporation manufactured another version of this flare. The grain composition consists of 62% magnesium, 33% Teflon®, and 3% anthracene. The aluminum case is 7.5 inches long by 1.56 inches in diameter. The device weighs 2.05 pounds. This flare is used on the TDU-4/B Tow Target.

**W206 Flare:** The Atlantic Research Corporation developed W206 flare was designed and developed for the Aeronautical Systems Division at Eglin Air Force Base. The flare is stated to possess an improved long-wavelength infrared emission and to be relatively insensitive to changing altitude and high air velocities. It is designed for altitudes above 40,000 feet and speeds in excess of Mach 1. Ignition is by the Navy Mk 2 Mod 0 electric squib. The grain is in a stepped aluminum case that is 2 inches in diameter at the front end. The case steps down to 1.75 inches in diameter at the rear end. The case is 9.5 inches long. A layer of glass epoxy liner

separates the grain and the aluminum in the wider position of the tube. The device weighs 2.0 pounds.

**W211 Target Augmentation Flare:** Mr. B. Dubrow, US Flare Division of the Atlantic Research Corporation, developed this flare. He later transferred to the Space Technology Laboratory. The device is 2-inches in diameter by 13-inches long and weighs 2.5 pounds. The grain weighs 1.77 pounds, has an output of about 1000 W/sr in the 1.8 $\mu$ m to 2.7 $\mu$ m bandpass region, and has a burning time of 90 seconds. The grain composition consists of 54% magnesium gran 15, 30% Teflon®, and 16% Kel-F® wax. Two USF Model 706 Squibs wired in parallel for reliability ignite the W211 flare. The W137 flare is ignited with only one squib. No less than three W211 flares are used to augment the F9F-6K target per firing pass at 30,000 feet. The W211 flare is used extensively as an infrared source in the Pogo-Hi Target Rocket. It also is used on tow targets.

**W211 Tracking Flare:** This is a commercial item manufactured by the US Flare Corporation that weighs about 2.75 pounds, is about 2 inches in diameter by 12.75 inches long. It is ignited electrically.

**W211/A-5 Tracking Flare:** This flare was manufactured by the US Flare Corporation as a developmental item for the Air Force. It is 2 inches in diameter by 7.06 inches long, weighs about 1.6 pounds, and is ignited electrically.

**W211F Flare:** The Atlantic Research Corporation manufactured the W211F flare. It is used on the Q-2C drone. The grain composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® wax. The aluminum case is 10 inches long by 1.83 inches diameter. The device weighs 2.5 pounds.

**W211S Target Flare:** The W211S flare is similar to the NOTS Model 712A flare and is intended for testing the increased-range Sidewinder 1C missile. It is attached to the QF-9F target drone, the Beech KDB drone and the Ryan target drone BQM-34A (old designation Q2C) jet powered aerial target with a subsonic speed. Flare-Northern Division of the Atlantic Research Corporation supplied this flare. Mr. Allen of NOTS was the task manager.

**W213 Tracking Flare:** Flare Northern Division of the Atlantic Research Corporation developed this device. This developmental flare is aluminum cased. It was designed with a base electrical connector and an internal insulator sleeve of paper-based phenolic material to facilitate side-by-side mounting of the flares. This is intended to permit sequencing without danger of premature ignition. Replacement of Kel-F® wax was a consideration during development. The W213 flare was one of a series of Navy and commercial flares evaluated at China Lake. In a series, which included the NOTS Model 702A flare, the NOTS Model 711A, the NOTS Model 712A, and the ARC W211F flare as well as the W213 flare, the W213 flare is the only one with higher intensity in the 2 $\mu$ m to 3 $\mu$ m bandpass region than in the 3 $\mu$ m to 5 $\mu$ m bandpass region. Ignition is with the F-ND Model 706 squib made by the

Flare Northern Division of the Atlantic Research Corporation. The flare device is 2 inches in diameter by 11.25 inches long and weighs 2.0 pounds. The grain is 8 inches long.

**W216 Tracking Flare:** This is a double-end burning ejected flare made by the Atlantic Research Corporation. The W216 is identical to the E216 flare. The MTV grain is 1.625 inches in diameter by 3 inches long and weighs 0.22 pounds. The composition is EW-50 consisting of unspecified materials or proportions.

**W224 Countermeasure Flare aka F-ND Model W-224 Flare:** This infrared flare was developed and manufactured by Dr. Waite and Mr. Reed of the Flare Northern Division of the Atlantic Research Corporation during 1966. The grain is 17 inches long by 2.125 inches in diameter and weighs 5.2 pounds. This flare is unique in configuration, consisting of an internal-burning star cast grain. The flare is part of the ADR-9A countermeasure rocket system, which is compatible with the B-52 AN/ALE-25 pod mounted dispenser. The unit, including the chaff dispenser system, the flare, and the rocket propulsion system is 6-feet long by 2.75 inches in diameter. The internal burning performance provides the infrared signal without weakening the walls of the entire structure during the 12-second life of the countermeasure system.

**W251 Flare:** The Flare Northern Division of the Atlantic Research Corporation developed the W251 flare. The composition, cast in an aluminum case, is a mixture of predominantly magnesium and fluorohexylmethacrylate. The metal fuel and the liquid fluorocarbon are mixed and poured into the flare casing and allowed to solidify. After aging, the composition separated from the case leading to serious deterioration of the flare. Subsequent research corrected this problem. The grain composition may be similar to that in the TAU-56/B 105E flare. The device is 2.5 inches in diameter by 19.75 inches long and weighs 4.75 pounds.

**W251 106E Flare:** Ordnance Research Inc. provided this flare, which simulates the W251 flare system. The unit is in the form of a 6-inch long cylinder the outside diameter of which is 1.125-inches. It contains a castable magnesium-fluorocarbon composition.

**AF 08-(635)-1402 Flare:** This is an infrared flare provided under a developmental contract: It was made about 1960 by the Denver Research Institute in a 2-inch diameter by 10 inch long Micarta case.

**AF Part No. 60D-22348 Flare:** This infrared flare was made about 1960 by Aerojet-General. It has a 2-inch diameter by 10 inch long steel case.

**AF Part No. 60D-22390 Flare:** This infrared flare was made about 1960 by Special Devices, Inc of Hughes Aircraft Company. It has a 2-inch diameter by 10-inch long aluminum case.

**AGC Flare:** Aerojet-General manufactured this flare. The grain composition consists of 64% magnesium, 34% Teflon®, and 2% anthracene. The nickel-plated steel case is 9 inches long by 1.38 inches diameter. The unit weighs 2.0 pounds. This flare is used on the TDU-4/B Tow Target.

**AGX0827 Target Flare:** Aerojet-General built this flare about 1963. It has an outer case diameter of 1.75 inches by 11.4 inch overall length. It is ignited by a squib through a two-contact bayonet connector in the base of the flare. The grain composition is approximately 65 parts by weight magnesium powder, 35 parts Teflon®, and 5 parts anthracene. The burning time is about 90 seconds. Flares made after July 1963 contain 3 or 4 parts by weight anthracene. Caution: The AGX0827 flare has erroneously been referred to as the TAU-50 flare and sometimes as the TAU-50/B flare during testing of the AGX0827 flare.

**BATS Flare:** Flare-Northern/Celesco designed the Ballistic Aerial Target System (BATS) flare. This flare, a blackbody type radiator, is an infrared augments for the BATS system.

**BB-9 Flare:** This flare is also known as the Mk 3 Mod 0 target flare.

**Beech 6 Target Flare:** This flare was designed and built about 1961 by Special Devices Incorporated for the Beech Aircraft Corporation's XKD2B-1 Navy drone. The Beech 6 flare was made to facilitate infrared radiant intensity measurements. It probably is similar in size to the Special Devices 5B1-5.1 infrared augmentation flare.

**Beech 19 Target Flare:** This flare was designed and built about 1961 by Special Devices Incorporated for the Beech Aircraft Corporation's XKD2B-1 Navy drone. The Beech 19 flare was made to facilitate infrared radiant intensity measurements. It probably is similar in size to the Special Devices 5B1-5.1 infrared augmentation flare.

**CDC Model 155 Infrared Emitter:** The final model of this device, made by the Cooper Development Corporation (CDC), Monrovia California was put on the pogo-hi rocket target.

**DF Flare aka Type DF Flare:** This Kilgore flare named type DF contains potassium nitrate, charcoal and rosin. A variant contains silicates that were added to the DF mixture. Other variants were magnesium, strontium nitrate, potassium perchlorate, sulfur, potassium nitrate, lithium carbonate, and charcoal added to the DF mixture.

**F-ND Model W-224 Flare:** This infrared flare was developed and manufactured by Dr. Waite and Mr. Reed of the Flare Northern Division of the Atlantic Research Corporation during 1966. It is 17 inches long by 2.125 inches in diameter and weighs 5.2 pounds fully loaded. The flare has an internal-burning cast grain

configuration. The flare is part of the ADR-9A countermeasure rocket system, which is compatible with the B-52 AN/ALE-25 dispenser.

**Flare Northern Cavity Flare:** The cavity flare was designed by the Air Force Armament Laboratory and was fabricated by the Flare Northern Division of the Atlantic Research Corporation. The flare is a somewhat flat cylinder 3.25 inches thick by 6.5 inches in diameter with a 1.7 in diameter hole in the center of the grain. An unspecified composition was cast in a 7-inch diameter phenolic case. Three of these flares were tested in a comparison with the Aerojet TAU-56/B flare. The results indicated similar burning times but the cavity flares had very much lower radiative intensities.

**Flare Northern Rectilinear Flare:** This cast flare is designed for use with the AN/ALE-11 pneumatic dispenser. A mechanical acceleration sensitive safe-and-arm initiator ignites the castable fluoromethacrylate-magnesium pyrotechnic charge. The Illinois Institute of Technology Research Institute developed the safe-and-arm initiator. The external dimensions of the flare are 2 inches high by 2.99 inches wide by 5.02 inches long. It weighs 2.2 pounds. The two 2.99-inch and 5-inch faces are formed with a grid of sixty-three 0.188-inch holes during the casting process to increase the burning surfaces by 70% for a concomitant increase in the initial intensity. The use of the methacrylate ester of 1,1,3-trihydroxytetrafluoropropan-1-ol provides excellent stability up to 430 °F.

**FW282 Flare:** This flare contains an undefined grain composition that is loaded into a modified 40mm Mk 112 photoflash cartridge case. The grain composition in the FW282 flare is different from the grain composition in the FW355 flare. The cartridge is ejected by a Forward Air Controller (FAC) aircraft from a W/A-6 Lambert photoflash dispenser. The flare casing is 1.568 inches in diameter by 3.850 inches long with a rim diameter of 1.70 inches. In early 1974, Mr. George W. Schivley of WPAFB stated that this flare or the FW355 flare, when used in conjunction with a missile-warning receiver, would give the FAC a fully automated IRCM system.

**FW355 Flare:** This flare contains an undefined grain composition that is loaded into a modified 40mm Mk 112 photoflash cartridge case. The grain composition in the FW355 flare is different from the grain composition in the FW282 flare. The cartridge is ejected by a Forward Air Controller (FAC) aircraft from a W/A-6 Lambert photoflash dispenser. The flare casing is 1.568 inches in diameter by 3.850 inches long with a rim diameter of 1.70 inches. Mr. Schivley of WPAFB stated that this flare or the FW282 flare, when used in conjunction with a missile-warning receiver would give the FAC a fully automated IRCM system.

**Infrared Augmenter 3090N Flare:** This augmenter was made about 1967 by DynaTech Inc (DTI) Tempe Arizona, the predecessor to Talley Industries, Mesa Arizona. The Infrared Augmenter 3090N flare, a blackbody type radiator, is made for use on the Northrup MQM-74A Chukar unmanned aerial vehicle target.

**K2 Flare:** Kilgore made this experimental countermeasure flare.

**PA-E-35392 Flare:** This infrared flare is a Picatinny Arsenal development. It is 1.125 inches in diameter by 6 inches long and has a minimum burning time of 22 seconds. It was made for a special test in the early 1960s for the Electromagnetic Laboratory, Research and Development Directorate, U. S. Army Ordnance Missile Command (AMC), Redstone Arsenal Alabama. Internally, the flare has two compositions, one of which has a greater output than the other. The higher output composition is loaded so that it will burn last, that being when the missile is at the greatest range. No information about composition specifics is available.

**Pace-IITRI Countermeasure Flare:** This is a high-performance infrared flare developed by the Illinois Institute of Technology Research Institute for the Pace Corporation and designed for compatibility with the Lambert XM-185 photoflash cartridge ejection set. It provides a rapid rise to a very high intensity and a uniform rate of intensity decrease from the peak to burnout at 6 seconds. The design includes a pneumatic bore-riding, fail-safe igniter. Grain elements of different densities and varying burning areas are used to generate the rapid rise and controlled decay in the intensity curve. An electric primer and a black powder charge eject and ignite the flare housed in an aluminum can, which falls away when the flare is airborne. The case is 3.1 inches in diameter by 9.98 inches long. The device weighs 4.3 pounds. The grain is 2.75 inches in diameter by 9 inches long and weighs 3.20 pounds. The grain consists, in parts by weight, of 66.1 parts magnesium, 22.6 parts Teflon® #5, and 11.2 parts Teflon® #7. The first fire mixture is 97% aluminum-tungsten oxide and 3% polyvinylfluoride binder.

**Target Marking Flare with no designation:** In the mid 1960s, NOTS developed an infrared target marking flare for SANDIA. It was made to dispense a special dispersion of the flare material upon impact with the target. The dispersed material was required to have a specified output and duration. No additional information is known about this development.

**T-245-3 Pyrotechnic Flare:** Del Mar Engineering Laboratories manufactured this flare. The size is 1.75 inches in diameter by 10.5 inches long. It has electrical ignition and weighs about 1.5 pounds.

**UMC-94 Tracking Flare:** This is a commercial item manufactured by the Universal Match Corporation. The size is 1.75 inches in diameter by 10.5 inches long. It weighs about 1.8 pounds and is electrically ignited.

**UMC-95 Tracking Flare:** This is a commercial item manufactured by the Universal Match Corporation. The size is 1.75 inches in diameter by 10.5 inches long. It weighs about 0.61 pounds and is ignited parasitically.

**UMC Pelleted Flare:** This is a commercial item manufactured by the Universal Match Corporation. It contains 0.46 pounds (210 grams) of 0.125-inch pellets and

0.89 pounds (40 grams) of igniter mix. The pellets are bound together in a solid candle by means of the ignition composition. The ignition composition acts as a binder. Mentioned in 1956 report.

**UMC-ASC 129 Flare:** This is a commercial item manufactured by the Universal Match Corporation. A test version was modified for high altitude ignition. Mentioned in 1956 report.

**UM-111 Flare:** A test unit of this 2-inch by 2-inch by 5-inch flare was provided by Unidynamics Phoenix. The Universal Match Corporation produced it. The flare consists of a plastic case, which is expended at ignition. The grain burns over the entire surface. Ignition is by the Illinois Institute of Technology Research Institute developed inertial bore-safe igniter. The unit weighs 1.8 pounds. It fits the USAF 669A Phase I dispenser.

**UNI Flares: Types I and II:** The UNI flares are a series developed by Picatinny Arsenal and manufactured at the Longhorn Army Ammunition Plant, Marshall Texas. The flares were developed for compatibility with FAC and similar aircraft. The flares are small and inexpensive, with a configuration similar to the Navy Mk 50 Mod 0 flare and the Army XM-196 mini-flare. The compositions are similar to those in the Army XM-196 mini-flare. In flight, at air speeds of 140 to 190 KIAS, both flares appeared to increase in intensity with time. The design is about 1974 vintage.

**UNI Flare Type I:** The grain consists, in parts by weight, of 74 parts magnesium, 26 parts Teflon® and 2.6 parts nitrocellulose. The first fire is composition SI-119. The grain composition and first fire are pressed together as one increment. The grain is about 1.4 inches in diameter by 2.0 inches long and weighs 0.15 pounds. The complete unit is 1.57 inches in diameter by 3.47 inches long. For test purposes, the grains were loaded into M-112 photoflash cartridge cases.

**UNI Flare Type II:** The grain consists of a half and half mixture of two different compositions. One mixture is made up, in parts by weight, of 74 parts magnesium, 26 parts Teflon® and 2.6 parts nitrocellulose. The other mixture is made up, in parts by weight, of 74 parts magnesium, 26 parts Teflon® and 2.6 parts Viton® A. The first fire is composition SI-119. The grain composition and first fire are pressed together as one increment. The grain is about 1.4 inches in diameter by 2.0 inches long and weighs 0.15 pounds. The complete unit is 1.57 inches in diameter by 3.47 inches long and weighs 0.3 pounds.

**Unidynamics Decoy Flare:** This is a 1966 vintage decoy flare that fits the AN/ALE-29 chaff and flare dispenser. It had a limited production of 10,000 units. The Unidynamics flare was made for comparison to the NOTS EX 46 Mod 0 decoy flare. Unidynamics considers the overall flare design, grain configuration, and grain formulation to be proprietary.

**United Technology Corporation Hybrid Flare:** This hybrid flare consists of a cylindrical hollow flare grain wherein flowing gaseous oxygen is ignited by burning propane. The units are 24 inches long by 3.5 inches in diameter. The grains consist of polybutadiene, polybutadiene-acrylonitrile, and polymethylmethacrylate with various amounts of aluminum as a fuel. The operation of these units can be started and stopped.

**XKD-2B-1 Target Augmentation Flare:** Special Devices Inc. manufactured this flare. It was developed for the Beech XKD2B-1 expendable powered target drone. It consists of fifteen prepelleted increments pressed into an aluminum tube that is 2.5 inches in diameter by 20 inches long. The device weighs 8.44 pounds. The grain weighs 6.95 pounds. The first fire composition, in parts by weight, is 33 parts magnesium, 14 parts Teflon® #1, 3 parts polyisobutylene, 5 parts amorphous boron, and 45 parts barium chromate. The grain composition, in parts by weight, is 12 parts magnesium, 25 parts Teflon® #1, 6 parts polyisobutylene, 5 parts amorphous boron, and 45 parts barium chromate. The flare is ignited with two Special Devices squibs. The flare passed performance and safety tests and was approved for release for Navy use. Later however, the flares failed to sustain ignition at 50,000 feet and 70,000 feet simulated altitude.

**223 Thermopot Flare:** This is a thermite flare that has a burning time of 360 seconds.

**5B1-5.1 Infrared Augmentation Flare:** This flare was designed and built by Special Devices Incorporated for the Beech Aircraft Corporation's XKD2B-1 Navy drone later designated the AQM-37A (USAF designation is WS-462L). The expendable powered target is capable of operation at 80,000 feet altitude and Mach 3. Very high altitude ignition is a requirement for the flare. The Special Devices 5B1-5.1 flare size is 2.5 inches in diameter by 20-inches long and weighs 8.4 pounds. The flare is spring loaded to provide a continuous advance during burning. Due to poor performance, China Lake started work on the 5B1-5.1 flare in order to develop an improved flare named the 5B1.5.1-1 infrared augmentation flare.

**5B1.5.1-1 Infrared Augmentation Flare:** The flare contains 6.5 pounds (2,955 grams) of prepelleted composition pressed at 9,250 psi. The improved grain composition consists of 12% magnesium, 5% boron, 45% barium chromate, 25% Teflon®, 7% glass beads and 6% polyisobutylene. Special Devices Inc. provided 3 flares with the improved composition for test firing at a simulated altitude of 70,000 feet (33.6 torr) in the China Lake High Altitude Research Project (HARP) chamber. The improved flares successfully ignited at high altitude but were deficient in their radiative output in the 3 $\mu$ m to 5 $\mu$ m bandpass region. Nevertheless, the improved 5B1.5.1-1 flare was determined to be safe for Service use. Even when using boron, the composition did not produce the desired 900 long-band to 250 short-band ratio but instead produced about a 1:1 ratio. To overcome these deficiencies, the NOTS Model 729 target augmentation flare was developed to replace the Special Devices

5B1-5.1 flare and the improved 5B1.5.1-1 flare. The Navy Bureau of Weapons designated the improved 5B1.5.1-1 flare as the Mk 37 Mod 0 Target flare.

**Flare of unknown designation:** This developmental flare is dispensed from an AN/ALE-20 dispenser fitted onto a B-52 bomber. The dispenser has 17 tubes, holds 52 flares at 3 flares/tube. Ejection velocity is about 80 feet/second. A commutator band is used to ignite each flare. Each flare consists of 0.42 pounds (190 grams) of a cast fluoromethacrylate. The grain burns internally.

# EXCHANGE OF INFORMATION

## NOTS Technical Reporting

The Naval Ordnance Test Station was commissioned during World War II in November of 1943. The Test Station is an outgrowth of the rocket program being conducted at Inyokern, China Lake by the California Institute of Technology (Caltech) for the Office of Scientific Research and Development (OSDR). From the time of its commissioning, until the end of WW II in August 1945, NOTS did little technical reporting, for its main role was to support the weapon development and pilot production work of Caltech. Caltech published the reports between 1943 and 1955. With the transfer of most of the Caltech work to NOTS in 1955, the Station began its own reporting program. The NOTS Technical Publication series starts in 1958.

## Infrared Information Symposia

The importance of the growing interest in research and development of military technologies and their rapid expansion is evidenced by the formation of a symposium series in 1949 known even today as the IRIS conferences. The Office of Naval Research (ONR) sponsors the Infrared Information Symposia (IRIS). These meetings are open to U. S. government employees and U. S. government contractors. The conferences address infrared topics such as detectors, active and passive jamming, expendables such as chaff and infrared decoy flares, measurement techniques, and all associated equipment development. The history of IRIS and the history of ONR can be found in the proceedings of IRIS.<sup>8</sup>

## Meetings on Infrared Suppression

In October 1960, ONR sponsored the First Meeting on Infrared Suppression. Attendance eligibility is similar to that of the IRIS symposia. The second meeting took place in June 1962. Lockheed, Burbank, California, hosted the Third Meeting on Infrared Suppression. Mr. Francis Linton of the Wright Air Development Center, WPAFB and Mr. Regelson of NOTS China Lake were the co-chairmen for the Third Meeting on Infrared Suppression.

## Pyrotechnics Lecture

In February 1955, Dr. David Hart while at the Samuel Feltman Ammunition Laboratories at Picatinny Arsenal, Dover New Jersey presented Research and Development Lecture No. 24 entitled Research and Development Progress in Pyrotechnics. Formally organized since 1951, the Picatinny Arsenal Pyrotechnics

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<sup>8</sup> The history of IRIS and the history of ONR can be found in the Proceedings of the Infrared Information Symposia Volume 1, Number 1, 1956 and Volume 21, 1977.

Section conducted research and development of pyrotechnics. The Pyrotechnics Section is organized into Engineering, Chemical Research and Radiation Research units. Picatinny Arsenal, a U. S. Army agency, is responsible for research and development of all military devices and compositions for the Army and the Air Force, as well as all pyrotechnic compositions for the Navy. In fact Picatinny Arsenal only supplied a limited number of compositions and devices to the Navy. Tracking flares for trajectory observation of rockets and guided missiles are mentioned as a pyrotechnic category in Dr. Hart's lecture. He did not provide information about work on these items for the Navy.

During Lecture # 27 in February 1956, Dr. Hart reviewed development of delay compositions, the stoichiometry of fuels (metals and non-metals) and oxidants used in delay compositions. He pointed out that black powder customarily used to make delays, is an explosive and presents some hazards. To overcome the disadvantages of black powder as a delay powder, Dr. George C. Hale at Picatinny Arsenal, began work in 1929 on the development of non-gaseous delay powders, making use of inorganic exothermic reactions similar to those used in thermite mixtures. The first non-gaseous delay powder was developed in 1931 for the M16-A1 primer detonator used in a bomb fuze. It contained red lead, silicon, and glycerine, the latter added as a binder. Even in small quantities, organic binding agents such as glycerine and linseed oil produce a significant amount of gas upon combustion.

### **Symposium on Basic Pyrotechnics Research**

On 14-15 February 1957, Picatinny Arsenal hosted a symposium on Basic Pyrotechnics Research.

### **Semiannual Interstation Pyrotechnics Conferences**

The purpose of these Conferences is to disseminate new information on techniques, interchange of ideas in research and development, and discuss mutual problems in the field.

The Third Semiannual Interstation Pyrotechnics Conference was held 5-7 April 1960 at NOTS. During the 1960 conference, Mr. Smith of NAD, Crane presented problems encountered in making luminous intensity and infrared measurements. The test tunnel configuration, positioning of the test unit, smoke obscuration, smoke exhaust, and measurement instrumentation are some of the topics discussed. Mr. Pennington of NOTS presented an overview of pyrotechnic target augmentation at NOTS. Mr. Eli D. Besser of NOTS presented information about mixing variations using the Simpson Muller mixer, the Lancaster Muller mixer, and a 40-gallon High Explosive Melting Kettle. Mr. Besser reported that volatility and migration of Kel-F® wax, which has a melting point of 100-140 °F, does not occur. Later, problems with Kel-F® wax did arise making the Viton® A replacement for Kel-F® wax even more important. Mr. Bernard E. White of NOL White Oak described work on development

of delay columns. Igniter mixes called A1A, F33B, and FA878 were considered along with D-16 delay powder. Mr. Rivette described the variation of flare performance with diameter. Mr. Allen of NOTS reported on a flare case material study. Materials considered were stainless steel, aluminum, magnesium, brass, Lucite, Teflon®, and Micarta. Mr. Russell N. Skeeters described ordnance fixes for HERO, just 3-years after the USS Kearsarge CV33 incident.

The Fifth Interstation Pyrotechnics Conference was held 5-6 December 1961 at NAD, Crane. Mr. Allen of NOTS presented a paper on an improved flare composition, that being 54% magnesium gran 16, 30% Teflon® #7 (35µm), and 16% Viton® A. This is the "improved" formula, which came into being with the shock-gel process. The shock-gel process was reported in 1959.

The Seventh Interstation Pyrotechnics Conference was held 21-23 January 1964 at NAD, Crane. Mr. E. M. Kane of the Naval Missile Center (NMC), Point Mugu, California presented papers on spectral analysis of flares and infrared flare performance. There also is a presentation on scanning spectroscopy by Mr. Benham of NAD Crane.

The Eight Interstation Pyrotechnics Conference was held 8-10 December 1964 at the fleet Antisubmarine Warfare School in San Diego California. Mr. Allen of NOTS presented a paper on new possibilities in underwater flare formulations. He reported that composition PL6239 was underwater for 69 days and still ignited. That composition consists of 54% magnesium gran 16, 30% Teflon® #7, and 16% Viton® A.



## **PRINCIPAL RESEARCH AND DEVELOPMENT AGENCIES**

Scientists, engineers and technicians at China Lake pioneered target flare, augmentation flare, and decoy flare development in addition to other technologies. It naturally followed that there would be a concentration of developmental effort of these devices at China Lake. In the early times, the NOTS effort was the result of their local needs and those directed by Navy headquarters in Washington DC. Because of their expertise, NOTS investigators were also able to undertake tasks from the Army and the Air Force. It should be noted that there was a capacity within NOTS to physically accomplish tasks involving energetic materials such as propellants and flares. The Air Force did not have a capability within their organization to conduct developments involving energetic materials. As a result, the Air Force conducted their flare development by contract with outside research institutes. Because of these circumstances, the major Navy efforts were performed at NOTS and NAD Crane, the Army efforts were performed by the Samuel Feltman Ammunition Laboratories at Picatinny Arsenal and by the Universal Match Corporation, and the Air Force conducted their decoy developments under contracts mainly with the Armour Research Foundation and Denver Research Institute.

### **Naval Ordnance Test Station (NOTS)**

About 1969, the Naval Ordnance Station, China Lake became the Naval Weapons Center (NWC), China Lake.

### **Early Tracking Flares**

NOTS was involved with infrared target augmentation since 1954. They needed to provide a target source for the F6F-5K drone. The T-131 tracking flare was the first infrared source for drone use. Multiples of the T-131 tracking flares were needed to provide a suitable target. In 1956, the Army reported an M136 (T131) tracking flare with illuminating composition.

Initially, flares were needed for tracking in the visible portion of the electromagnetic spectrum. Later, infrared radiators were needed to enable tracking in the infrared region. Tracking flares serve two major purposes in missile research. They facilitate tracking by optical instrumentation operators who might not otherwise be able to track the missile in flight at high altitude or under all but the best atmospheric conditions. Also, data reduction personnel would often find it difficult, if not impossible, to locate events on the film records if there were no flares to provide a reference mark on the film. In 1960, Mr. Pennington of NOTS stated that the T-131 flare, the Mk 21 Mod 0 flare and the NOTS Model 702 flare are the most widely used tracking flares at NOTS.

## The Shock-Gel and Extrusion Process

In 1959, a shock-gel process was discovered that could produce an improved infrared composition that contained Viton® A instead of Kel-F® wax. The improved composition consists of 54% magnesium gran 16, 30% Teflon® #7 (35µm), and 16% Viton® A. This composition has less electrostatic sensitivity than the Kel-F® formula. It can easily be extruded at temperatures from 150 °F to 225 °F as well as being compression molded. The extruded forms have tensile strengths and elongation that withstand forces and vibrations frequently experienced during use such as during a sled-test run. In addition, the extruded forms can easily be machined. This discovery became the foundation for processing of infrared compositions and future infrared flare development. The shock-gel process, sometimes known as the coacervation process, continues in use today.

In 1962, Mr. Allen of NOTS described the shock-gel process as follows: Viton® A, a copolymer of vinylidene fluoride and hexafluoropropylene, also known as perfluoropropylene, is dissolved in acetone to form a solution ranging from 8 to 20% solids. The required quantities of magnesium and Teflon® are stirred into the appropriate quantity of Viton® A solution. This slurry is quickly added to a large volume of rapidly agitating hexane. By this treatment, all the material is precipitated in a granular form. After one or two more washes with additional hexane, the material is collected and dried. While drying, the material is usually passed through a brass screen with 0.250-inch openings.

The granular material is then heated to 190 °F, placed in the barrel of an extrusion press (heated to 225 °F), and extruded through the die. The extrusion pressures and flow rates are dependent upon (1) the total binder content, (2) the Viton® A to Teflon® ratio, (3) the particle size and particle shape of the filler, (4) the ratio of the die area to barrel area in cross section, and (5) the shape and design of the die itself. After extrusion is completed, the material may be machined into desired lengths and shapes as required.

The shock-gel process is also used at China Lake to extrude propellants with fluorocarbon binders. They demonstrated extrusion of a composition consisting of Teflon® and Viton® A as binders, aluminum and zirconium as fuels and ammonium perchlorate as an oxidizer. Work continued at NOTS in 1966 and beyond to improve the procedure. The hazards of alcohols in wet mixing of magnesium compositions were recognized and studied.

## Standard and Improved Infrared Composition

Prior to about 1959, the infrared composition that had evolved from an illumination composition consisted of magnesium, Teflon®, and Kel-F® wax. That formula was considered by NOTS to be their "Standard". This "Standard" infrared composition consisted of 54% magnesium gran 16, 30% Teflon® #1 600µm, and 16% Kel-F® #40 wax. The tensile strength of this composition is quite low and the density is only about 90% of theoretical. The composition is quite hazardous, exhibiting a 50%-point electrostatic sensitivity of 0.76 joules. Flares of this composition are usually made by compression molding. There was a need to improve this composition to overcome its deficiencies. About 1955, while considering many variations of the infrared composition, mixtures of 48% aluminum-52% Teflon®, 56% boron-44% Teflon®, and 54% zirconium hydride-46% Teflon® were studied.

A new infrared flare composition for tracking flares was first conceived by Mr. Julian of NOTS China Lake about 5 July 1960. It was extruded for the first time on 10 November 1960. This new infrared composition consists of magnesium, polytetrafluoroethylene, and Viton® A. It provided a substantial increase of radiated energy in the infrared over former tracking flare formulae that typically consisted of an illuminating flare composition or a magnesium-Teflon®-Kel-F® wax composition. The new composition by Mr. Julian is the first with the exact formula 54% magnesium, 30% Teflon®, and 16% Viton® A. He also explored an alternate infrared composition, that being a binary mixture of 36% Viton® A and 64% magnesium. That composition, which also could be extruded, burned faster than MTV with a higher radiative output but with a lower energy output in the measured wavelength band. Ignition could be achieved at 80,000 and 100,000 feet altitude with an ignition composition consisting of 10% boron and 90% barium chromate. Mr. Julian mentions the shock-gel process for making infrared composition in his descriptions of the above compositions.

On 21 November 1961, Mr. Judson H. Eldridge and Mr. Julian<sup>9</sup> of NOTS filed for a patent which discloses how additives to Teflon® such as Viton® A can be used to extrude Teflon® easily. They mention adding fillers such as metal, carbon and inorganic salts to the binary Teflon®-Viton® A composition and demonstrated extrusion of the composition containing tungsten and lead fillers. This patent can be considered to be the invention of the flare compositions that could be fabricated by an extrusion process that facilitated the decoy manufacturing process.

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<sup>9</sup> Eldridge, Judson H. and Elmo C. Julian. Polytetrafluoroethylene Composition Containing Vinylidene Fluoride-Perfluoropropylene Copolymer. U. S. Patent 3,291,864. 13 December 1966. The patent was filed on 21 November 1961.

## Various Developmental Tasks at China Lake

Efforts at China Lake to develop new flares, to make product improvements to existing flares and to better understand the associated technology was a continuing process. Many tasks related to flares often were ongoing at the same time with a wide range of objectives. Some samples of these projects although incomplete are described below.

As flare performance optimization studies continued, NOTS investigators developed triangular compositional diagrams to show the optimum infrared formulae using magnesium, Teflon®, and Viton® A (MTV). Similarly, a triangular diagram was constructed to show the burning rate as a function of Teflon® particle size. Recommendations included replacement of the Kel-F® wax with Viton® A and incorporation of graphite nuclei systems such as anthracene and phenanthrene to enhance the yield, as reported by the Air Force.

During attempts to formulate infrared radiating compositions, NOTS researchers learned that a composition originally formulated for radiation in the visible could be converted to a composition that would radiate in the infrared by adding hollow polystyrene beads. An example of such a composition is PL 6502. This method to improve flare radiative performance never was implemented.

As part of the effort to improve processing of infrared flare materials, during the mid 1960s, Mr. Breslow and Mr. S. R. Stanley of NOTS conducted isostatic-pressing studies of large flares under the sponsorship of Mr. William Lurie in Naval Air (NAVAIR) Headquarters.

NOTS investigators also undertook tasks different from but related to infrared decoy technology. About 1963, the Marine Corps had a requirement for a night attack flare that would be an illuminating flare with a low rate of descent or would hover. To fill that need, NOTS researchers considered a hot air balloon and rotary wing suspension. They also considered the Army T-10E4 (M138) aircraft parachute flare and the T-10E6 (M139) aircraft parachute flare for this application.

A recurring problem with decoy flares was the failure to ignite at high altitudes where flares are required to operate. As part of the studies to aid ignition, Mr. Foote and Mr. Wiebke of NOTS studied hot bridge-wire initiation of magnesium-fluorocarbon composition PL 6239, composition PL 6328, and composition PL 6503 for Mr. J. G. Boyes at SANDIA.

There also was a need for a wheels-up warning system. Such a device could be a mortar at the end of runways at the China Lake Naval Air Facility. The double star AN-M37A2 aircraft illumination signal was considered for this application. A full description of this concept is provided in the Mr. Sanford R. Allen and Mr. Kenneth R. Foote, China Lake, U. S. Patent 3,181,822 for "Wheels-Up" Flare Warning System of May 4, 1965.

In 1967, Dr. Handler of China Lake reported on the development of the NOTS Model 400A decoy flare intended for launching from the AN/ALE-29 dispensing set. The goal is for the flare to defeat the ATOLL missile using the Sidewinder 1A as a surrogate. The flare's composition consists of 55% magnesium, 30% Teflon®, and 15% Viton® A. The design includes a pull wire for ignition, which is similar to pull wire igniters used in Army devices. Flight tests were scheduled for May of 1967.

Early flare developments were aimed at providing protection in the infrared 2µm to 3µm bandpass region. As missiles improved, the threat moved to also operate in the infrared 3µm to 5µm bandpass region. In 1968, Mr. Hanzel, Dr. Handler and Mr. Harp set out to develop a family of infrared flares that were effective in the 3µm to 5µm bandpass region. They considered changing the burning mode to a much higher rate, burning more material, lengthening the flare by two inches, altering the AN/ALE-29 dispenser to "squarish" holes, and altering the composition to improve efficiency. The Mk 46 Mod 0 flare, which was in production at the NAD Crane in 1968, is the first flare developed with the above objectives. They discussed the need for 120-150 decoy flares on an aircraft operating in a dangerous area. That perhaps is the first time that IRCM investigators suggested that the number of decoy flares that could be carried by aircraft of that era would be insufficient to provide complete protection.

Dr. Handler and Mr. Hanzel of NOTS also considered making a longer flare grain and composition variants. For the Mk 46 Mod 0 flare with the larger grain, they considered four different igniters, namely the pull wire, stab primer, electric primer and the pilot flame. Work also was directed toward an improved composition or a grain configuration that would yield a 100-microsecond rise time. One such improvement that was mentioned in a 1969 report was to form twelve longitudinal slots on the exterior of the grain to get a quicker rise time. Variations of this concept proved in time to be an effective way to adjust performance.

As part of the continuing effort to improve decoy flares, NWC extruded grains with the Mk 46 Mod 0 flare type exterior and an 8-point star interior with six different ignition configurations. By late 1970, NWC was exploring many design concepts for a flare intended to perform in the 3µm to 5µm bandpass region. They removed the pull wire and designed the case and the impulse cartridge to be an integral piece. They tested many grain designs, including a 4-slot, 24-slot design and star perforation designs.

In early 1970, Navy Headquarters proposed that the new flare being developed must remain the same length in order to be compatible with the AN/ALE-29 dispenser. That meant the new flare needed to be 1.4 inches in diameter by 5.875 inches long. Since the flare is volume-constrained to the size of the holes in the dispenser block, they needed an alternate means to achieve higher performance through increased volume-efficiency. This resulted in the need for superior flare material, shorter burning requirements, or altering the reduced serviceability of

existing flares caused by degradation at altitude and velocity. The investigators used composition PL 6328 for the grain to achieve a higher performance in their new flare.

As decoy flare testing continued at NOTS, additional deficiencies or weaknesses in flare performance were uncovered. One of these was the affect of airflow on flare performance. To evaluate this feature, in mid-1970, a team of investigators was assembled to conduct laboratory studies of the airflow effect. The team consisted of Dr. Elliott Raison at the Illinois Institute of Technology Research Institute (IITRI), Mr. Balwanz at the Naval Research Laboratory (NRL) and researchers at NWC China Lake. The team confirmed the marked reduction of infrared radiant intensity when flares are exposed to airflow. This may be the first time this characteristic of decoy flares was confirmed.

One of the observations resulting from the continuing test efforts was that a decoy plume with a large radiating area would have some advantages over a compact plume, the latter often referred to as a point source. NWC investigators decided to study an extended area decoy flare in 1971. They used a mixture of gasoline with Navy aircraft fuel JP-5 in a 1:2 ratio to saturate sisal twine strands and cotton strands. They wrapped these in foil and then put them into the container. They tested this by attaching to the hook of the helicopter hoist line. The radiant energy from the burning area decoy broke the lock of the AIM-9C Sidewinder missile, which had been locked on the helicopter engine exhaust. The area decoy plume is about 15 inches across by 4 inches high. The radiant intensity on the 3 $\mu$ m to 5 $\mu$ m bandpass region is slightly higher than the 2 $\mu$ m to 3 $\mu$ m bandpass but 4 times higher than the 8 $\mu$ m to 12 $\mu$ m bandpass region. The results indicate that the basic idea of a low temperature, broad profile, extended area infrared signal may provide significant decoy value for protection of slow flying aircraft.

Another developmental thrust at NWC mentioned in a 1972 report involved the pyrotechnic generation of infrared radiation in the long wavelength region of 8 $\mu$ m to 12 $\mu$ m bandpass region or 8 $\mu$ m to 14 $\mu$ m bandpass region. To achieve this objective, investigators made a composition of aluminum and plaster-of-paris. That mixture is also known as Alcast. They made other compositions with Celcon®, boron, red phosphorus, silicon, molybdenum trioxide, calcium-silicon alloy, aluminum-calcium oxalate, ammonium formate, ferric oxide, potassium persulphate, sulphur, strontium carbonate and calcium carbonate.

## **Naval Ammunition Depot (NAD 1958-75), Crane Indiana: (NWSC 1976-1992)**

In an effort to better understand the performance of infrared compositions, in 1962 Mr. Jerry R. Kemp and Mr. John W. Feagans of NAD Crane performed a statistical analysis of the composition developed by NOTS for the Mk 28 Mod 0 tracking Flare. They varied the magnesium granulation, case diameter, and ratio of the magnesium-Teflon®-Kel-F® wax ingredients to find the effect on infrared emission and burning time. With the information gathered they attempted to construct empirical equations to predict flare performance.

Mr. Arnold and Mr. Kemp of NAD Crane evaluated the Mk 28 Mod 3 target flare performance about 1964. They tested the flare from ground level to a simulated 70,000-foot altitude in four increments. The altitude was simulated in a vacuum chamber.

Based on a Rocketdyne process, a Quickmix laboratory mixing technique was applied to the magnesium-Teflon®-Viton® A composition and delay compositions during 1969. A stirring motor in a beaker provided the mixing action. Heptane or acetone was the carrier liquid. Mr. Richard Kirby of NAD Crane reported the process works well with Viton® A and that they observed less batch-to-batch variability as compared to batches made by production processes.

In 1970, Mr. Sherman E. Dare and Mr. Patrick Arvin of NAD Crane converted a Hobart Model N-50 electric mixer to an air drive for preparation of pyrotechnic compositions. The Hobart is a planetary action mixer. The air drive was introduced for safety reasons.

About 1981, Mr. Donald R. Hazelton and Dr. Henry A. Webster III of the Naval Weapons Support Center (NWSC) Crane Indiana described design parameters for an outdoor transient velocity windstream test apparatus. The facility provides the ability to measure the radiant output of flares in an airstream of up to 0.9 Mach for nine seconds. The objective of this ground test is to obtain information about the degradation of the flare output due to the windstream when tested in the airborne mode. Later, the facility was upgraded to achieve 0.9 Mach for about 12 seconds.

In 1980, Mr. Kent Hammond of NWSC Crane reported the qualification of ground magnesium as an alternate to atomized magnesium in production flares. In 1981, MJU-8/B flare measurements were being made of production units by Mr. Forest Burton of NWSC Crane. A little later, Dr. Webster of NWSC Crane obtained an ultraviolet spectrum of the Mk 46 Mod 0 decoy flare and identified the atomic magnesium line in that spectrum and molecular emitters such as magnesium fluoride, magnesium oxide and magnesium hydroxide. A 1982 report describes an effort by Dr. Webster to obtain a statistical analysis of infrared flare production lot data, for example the MJU-8/B decoy flare. Earlier in 1979, he obtained the spectral distribution and an ultraviolet spectrum of an illuminating type pyrotechnic and in 1976 he obtained visible spectra of the Mk 46 Mod 1A decoy flare.

## Denver Research Institute (DRI)

For many years, the Denver Research Institute received contracts from the Air Force for investigating the fundamental aspects of decoy flare combustion. The source of most of these contracts was Mr. Sarnow of WPAFB. The thrust of the tasks was to find new and improved infrared flare compositions that might be applied to flare developments for bomber protection. This meant the flare compositions needed to produce a large infrared signature and that these flare compositions could be ignited at very high altitudes while operating at high Mach numbers. The breadth and depth of these studies is astonishing. Almost all elements in the periodic table were brought into consideration, as were almost all conceivable combinations of fuel and oxidizer. The thermodynamic features of these reaction combinations were tabulated. Some of the tasks are described below.

In 1959, a two-year contract was awarded to the Denver Research Institute for an Infrared Decoy Study with Dr. Robert W. Evans as the Principal Investigator. Mr. Sarnow as the Air Force Project Engineer at WPAFB sponsored the work. This was a project to study a wide variety of fundamental properties and behavior of the magnesium-Teflon® composition as described next.

Test pellets, 0.5 inch in diameter by 3 to 5 inches long, were prepared with magnesium and Teflon® but with no binder. The pellets were pressed at a dead load of 3000 - 4000 pounds. They attempted to determine the solid and gaseous products, the spectral distribution of the radiated energy and the temperature of the combustion. The combustion experiments were conducted in ambient air, flowing air, flowing nitrogen and flowing oxygen. By chromatographic analysis and other techniques, they accounted for all the magnesium but only about 85% of the fluorine in the solid reaction products. The difference was attributed to afterburning of the fluoride species with surrounding oxygen and nitrogen. The spectral distribution resembles a gray body of high emissivity with some selective emission around 2.5µm wavelength. The temperature immediately above the burning surface is in the range of 2200 to 2400 K.

The experiments also included burning the pellets in a six-foot diameter by six-foot long chamber capable of operation up to a simulated altitude of 250,000 feet. The Denver Research Institute team reported a slowdown of the burning rate and a spectral shift toward longer wavelengths as the altitude increases. They studied the linear burning rate of the pellet in argon and oxygen atmospheres and measured the burning surface temperature at different simulated altitudes (ambient pressure). They also explored how inhibiting coatings and axial holes affected pellet combustion and they attempted to measure the heat of activation of the magnesium-Teflon® mixture.

The Denver Research Institute team determined the intensity and spectral distribution of the radiation produced by flares made up of finely divided metal fuels and oxidizers for various ambient conditions. They discussed the contribution of

specific emitters and emission from various areas of the flame for simulated altitudes up to 150,000 feet and used mechanistic and kinetic studies to develop a proposed reaction sequence to qualitatively explain the reduction of radiation with altitude.

Another task mentioned in a 1961 report was an attempt to incorporate Viton® A into the magnesium-Teflon® mixture. Viton® A contains 65% fluorine and has a specific gravity of 1.85 g/cc. The Denver Research Institute team ground Viton® A that had been embrittled with dry ice without the benefit of a solvent medium. The ground Viton® A was put into solution of methyl ethyl ketone (MEK) and then was precipitated with ethyl alcohol or a water solution in MEK. Next the magnesium-Teflon® mix was added to the precipitated Viton® A, after which the pellet was cast into its container, and finally the solvent was removed. This technique never was implemented. The shock-gel process being developed at China Lake during the same time period eventually was chosen as the preferred process.

During their studies, Denver Research Institute investigators made an attempt to improve performance by changing the composition itself. They studied the effects of varying the magnesium from 36-70% and varying altitudes up to 100,000 feet. They recorded spectra, burning time, temperature, and radiated energy. They did not observe any effect by adding barium oxide but adding magnesium perchlorate appeared to be beneficial at altitude.

In a follow-on contract to the Denver Research Institute from Mr. Sarnow of WPAFB, Dr. Evans studied the fundamental characteristics of magnesium/Teflon® pressed flares. He reported (1) magnesium oxide forms instead of the expected magnesium fluoride when afterburning in air occurs, (2) replacement of Teflon® with Viton® A is not superior, (3) present methods of adding Viton® A to magnesium/Teflon® mixtures results in a product that is mechanically weak, (4) an equation for conduction of heat from the reaction zone, (5) that more radiant energy is emitted when the formula is nearer to stoichiometric than the 50:50 magnesium to Teflon® ratio being used in the study, (6) fuel rich mixtures are better than stoichiometric and produce a faster burning rate, (7) radiant energy output is best when there is afterburning with an adequate oxygen supply from the surrounding air and (8) that 50% of the radiation is from 15% of the projected flame area.

Experimental investigation of infrared radiating sources continued at the Denver Research Institute in the early 1960s pursuant to contracts from WPAFB with Mr. Sarnow as the project monitor. Mr. Robert M. Blunt and Dr. Evans of the Denver Research Institute determined heats of combustion of solid and gaseous products of the magnesium-Teflon® reaction and did a literature survey to locate information dealing with radiation from solids suspended in flames. Another contract with the Air Force emphasized the experimental investigation of infrared radiating sources. In this work, with a third investigator namely Mr. Jim P. Kottenstette of DRI, the Denver Research Institute team explored the fundamental technical, chemical and thermodynamic aspects of the magnesium-Teflon® reaction. They studied the

reaction products, attempted several methods to determine the activation energy, analyzed the spectral distribution of the radiated energy and explored the effects of particulate matter in the flame.

Mr. William H. McLain and Dr. Evans of the Denver Research Institute conducted a spectrometric evaluation of metal containing fuels in the early 1960s for Edwards Air Force Base California. They developed methods to use optical spectrometric techniques to evaluate the extent of thermal and chemical equilibrium for a methylamine-beryllium borohydride (Hybaline B-3) fueled rocket motor. They analyzed band and spectral line structure of selected species along with the total radiation distribution emitted from a small rocket motor. They compared experimental data to predicted and made estimates of chemical reactions that might be taking place. They observed two vapor phase combustion products in the visible, namely boron dioxide and beryllium oxide. In the infrared, they observed carbon monoxide and carbon dioxide selective emissions and emissions at the infrared wavelengths of 5.4 $\mu\text{m}$  and 5.9 $\mu\text{m}$  that they attributed to boron hydride oxide, boron oxide hydroxide, and boron monoxide. Mr. McLain and Mr. Ralph E. Williams attempted to determine whether exhaust plume species could be analyzed with a rapid scanning spectrometer and whether plume temperature profiles could be obtained utilizing Wien's Radiation Law or by a rapid-response multi-channel ratio pyrometer. They adapted the NASA propellant performance program onto their Burroughs B-5000 computer. They reported on photometric studies of the Hybaline B-3 air diffusion flames at ambient temperatures and studies of acetylene-oxygen flames to which boron and beryllium powders were added. From these flames they observed boron monoxide, boron dioxide, and beryllium oxide as the principal emitting species. They tabulated possible species in the visible and infrared from Hybaline B-3-nitrogen tetroxide, and hydrogen peroxide propellant systems and described a rapid-response three-color optical pyrometer that they used in support of their work.

By the mid 1960s, an understanding of missile operations and radiation emission from pyrotechnic flames was becoming more mature. As a result, the objectives of new research contracts became more specific. One such an example is the project sponsored by Mr. William S. Cronk of the Air Force Armament Laboratory at Eglin Air Force Base with the Denver Research Institute. Mr. Robert E. Knight, Mr. Blunt and Dr. Evans of DRI undertook the task to develop a pyrotechnic source that radiated in a narrow wavelength band and emitted selectively. The preferred radiation produced must be in the areas of interest, namely (1) in the specific infrared bands that result from the radiation produced by aircraft (and spacecraft) and (2) must also operate in the sensitive region of the detector used in the missile guidance system. The requirement of this effort may have been the first attempt to create a pyrotechnic decoy that radiated in regions that correspond to radiative regions where aircraft radiate. Today one might identify such a decoy as a "spectral or color adapted" flare. Perhaps in the mid 1960s the researchers did not appreciate how important it would be to have a decoy that would radiate with the proper spectral properties. The Denver Research Institute team observed in the

magnesium-Teflon® flare that the fluorine reaction competed with ambient oxygen and thus not much of the desirable carbon dioxide species was formed. To counteract this, they added manganese dioxide, barium oxide, cupric oxide, potassium perchlorate, and potassium nitrate to the magnesium-Teflon® formula in an effort to introduce more oxygen into the combustion reaction. These additions did in fact cause more carbon dioxide to be formed and they showed spectra to prove this.

As another approach, the Denver Research Institute team considered solid emitters such as boron nitride and discussed the disadvantages of such an approach. They also considered liquid flares. To explore other approaches, they compiled thermodynamic properties of hydrogen, carbon, nitrogen, silicon, phosphorus, and sulfur compounds that were stable at 3000 K and that emitted in the infrared. In the course of their investigations, they demonstrated that selective radiation due to carbon monoxide and carbon dioxide could be obtained from the magnesium-Teflon® reaction if they added an oxygen containing oxidizer such as potassium nitrate. As an additional approach, they suggested micro-encapsulation of perchlorofluoride into a fuel matrix. To show their insight into this problem, I quote, "the use of perchlorofluoride is suggested because it contains three oxygen atoms in addition to a chlorine atom and a fluorine atom. With a hydrocarbon fuel, carbon monoxide and carbon dioxide should be produced. While some of the hot carbon dioxide radiation is absorbed by the atmospheric carbon dioxide, much is still transmitted as the hot carbon dioxide peak shifted to the longer wavelengths (especially if carbon monoxide is present). As carbon dioxide is an intense thermal emitter and as part of the carbon dioxide radiation may also be due to chemiluminescence, it is desirable to include carbon dioxide."

Mr. Williams and Dr. Evans of the Denver Research Institute conducted an experimental investigation of infrared radiating chemical sources under the sponsorship of Mr. Sarnow of the Avionics Laboratory at WPAFB about 1963. They selected eight reactions for study based on volumetric enthalpies. These are reactions between aluminum-manganese dioxide, aluminum-cupric oxide, hafnium-manganese dioxide, magnesium-manganese dioxide, titanium-barium nitrate, titanium-cupric oxide, titanium-manganese dioxide, and zirconium-manganese dioxide. They obtained X-ray diffraction patterns and electromagnetic spectra and analyzed the gases and solids from the reactions. They studied aluminum fluoride, aluminum chloride and silver difluoride as additives and effects of gamma and neutron irradiation on manganese dioxide. Of the eight reactions, titanium-manganese dioxide exhibited the highest apparent radiation in watts per steradian and the highest radiant energy density in watt-seconds per cubic centimeter. These data nearly approach the volumetric efficiency of the magnesium-Teflon® reaction.

In the early 1960s as reported in 1965, Mr. William A. Schmeling and Mr. Knight of the Denver Research Institute started to explore different concepts for enhancing the performance of decoy flares. Mr. Cronk of Eglin Air Force Base supported this effort. They wanted to explore methods affecting the post combustion of

magnesium-Teflon® compositions and some non-carbon containing flares with the intent of enhancing the flare radiation of the electromagnetic spectrum as a function of altitude. Some of the approaches were to (1) include a two flare set-up wherein the plumes from the two flares positioned at 180 degrees impinged on one-another (“butting”), (2) introduce gas, liquid and solid additives to the post combustion zone such as carbon bisulfide, carbon tetrachloride, and benzene, (3) arrange a three-flare 120 degree “Y” opposed set-up and a four-flare cross opposed set-up, and (4) arrange a “tepee” of three-flares. The idea in all of these is for the plumes from individual flares to impinge on other plumes so that the point of intersection of the plumes would cause an increase in temperature resulting in increased radiation from the collective event. The “Y” and “cross” arrangements were the most promising. In addition, to get selective emissions, they explored magnesium-sodium nitrate and magnesium-potassium nitrate compositions that intrinsically were void of carbon; hence carbon emission would be reduced. Their goal as the work progressed was to get selective narrow-band high efficiency radiating characteristics. Their emphasis was on post-combustion phenomena, methods to enhance output energy, and to concentrate that energy into specific electromagnetic regions. To enhance the output, they considered gaseous additives such as oxygen, nitrogen dioxide, ammonia, chlorine, hydrogen chloride, chlorine trifluoride, sulfur dioxide, hydrogen sulfide, and propane. Dr. Hal Waite of Flare-Northern provided test flares for some of these experiments, which consisted of 45% fluoroheptylmethacrylate, 50% magnesium, and 5% isoviolanthrone made by the cast process.

In the mid-1960s, Mr. Sarnow of WPAFB sponsored a contract to study new flare materials. Mr. Williams and Dr. Evans of the Denver Research Institute and Mr. Stanley Lehrer of Astrosystems International Inc. conducted the work. To get around the greybody radiation from solid-solid reactions, they formulated liquid decoys from monopropellant nitromethane and even considered deuterated compounds such as deuterium chloride and deuterium perchlorofluoride. They reported boron compounds as being promising, these being compounds such as trimethylborate, triethylborane, and methylamine-beryllium-borohydride. Radiation from these occurred at wavelengths of 4.9µm and 5.4µm, a desirable radiative region.

## **Armour Research Foundation (ARF): Later became the Research Institute of IIT (IITRI)**

Dr. Katz and Dr. Elliott Raison of the Armour Research Foundation (ARF) at the Illinois Institute of Technology (IIT), Chicago Illinois, under contract to the Weapons Guidance Laboratory of WPAFB in late 1958, conducted an extensive 1-year task to originate and develop concepts for infrared flares optimized to radiate effectively in the 3.0 $\mu$ m to 5.5 $\mu$ m bandpass region. That study was to be primarily theoretical and analytical. The Armour Research Foundation team considered infrared sources classified into two groups, namely thermal and quantum. The Balls of Fire flare and secondary sources based on light scattering are examples of the first group. Chemiluminescence, fluorescence, and solid semi-conductor radiators are examples of the second group.

In addition to magnesium-Teflon® reactions, they also considered aluminum reactions with tungsten oxide, cadmium oxide, and ferric oxide. Some additional technology areas considered were thermochemistry, blackbody radiation, solid chemical reactions, gaseous chemical reactions, gaseous discharge, chemiluminescence, infrared fluorescence, controlled emissivity, controlled burning, combustible aerosol clouds, and light scattering. They also considered (1) a liquid flare made with magnesium powder mixed with a liquid polymeric form of Kel-F® wax and chlorotrifluoroethylene and (2) a cone shaped flare with an apex angle of 31 degrees. Presumably the latter shape would have less drag than a sphere and thus would separate from the aircraft more slowly in the horizontal coordinate.

In early 1960, Mr. Sarnow of the Air Research and Development Command WPAFB, awarded a contract to the Armour Research Foundation to develop the RR-96(XY-1)/Al flare for very high altitude applications. Dr. Raison of the Armour Research Foundation was the project engineer. To test the flares at extreme altitude, they fitted 16 flares into the nosecone of the 2-stage SPAROIR sounding rocket of the Sparrow missile family that could carry a 30-pound payload to an altitude of 74 miles. Modified magnesium-Teflon® flares were pretested in an altitude chamber. During a test at the Naval Missile Center, Point Mugu an aircraft at 33,000 feet altitude launched the missile that reached apogee at 392,000 feet with 57G acceleration and a 4,488 foot per second burnout velocity for a total flight time 317 seconds. The flares were ignited in pairs at 30,000-foot intervals starting at 100,000 feet altitude. Although there were equipment problems, most if not all the flares ignited as planned. Measurement of the flare radiation was unsuccessful. An alternate flare composition was also explored consisting of aluminum-tungsten trioxide with 0.5% Teflon® (added as a lubricant) that ignited at 160,000 feet and sustained combustion. The team at the Armour Research Foundation studied about 11,000 reactions in other related flare projects.

In 1961, Mr. Sarnow of the Aeronautical Systems Division (ASD) at WPAFB issued a two-year contract to the Armour Research Foundation for the study of new materials for infrared countermeasures. Dr Katz of the Armour Research Foundation was the leader of a large team of researchers. This was a study with a

very broad scope. They (1) tabulated reactions of thermodynamic significance, (2) performed experiments and made calorimetric measurements of reactive materials, (3) studied emissivity phenomena, (4) explored alkaline metal discharges of cesium and rubidium within electrical discharge tubes, (5) made a prototype of an infrared filtered flare wherein the composition was burned enclosed and the infrared radiant output was filtered, (6) considered metal reactions with fluorides and other oxidizers, (7) considered a liquid flare wherein the plume was formed by the burning slurry of particulate matter suspended in a suitable inflammable liquid substrate made with liquids such as methyl alcohol, acetone, benzene, and solids such as aluminum oxide, silicon dioxide and carbon, the latter three solids were intended to be the radiator and (8) made potassium chloride crystals for laser use.

As the work continued during 1961, the team (1) did a thermodynamic search of fluorides, phosphides, sulphides, carbides, nitrides, nitrates, borides, silicides, chlorides, oxides, peroxides, chlorates, perchlorates, chromates, dichromates, manganates, permanganates, borates, and perborates, (2) made flares of magnesium and Teflon® for comparison to binary mixes of aluminum-lead dioxide, aluminum-manganese dioxide, aluminum-cupric oxide, aluminum-cobalt(III) oxide, aluminum-tungsten oxide, aluminum-ferric oxide, magnesium-cobalt(III) oxide, and magnesium-ferric oxide, and (3) reported radiative band ratios, theoretical temperatures, and the area of the plume in square feet,

The work continued through 1962. The team acquired a Minneapolis-Honeywell high speed Visicorder chart recording system for use with the rapid scan spectrometer. This setup was used to evaluate the output of their test samples. The burning properties of seven additional oxide systems and about fifty metal-nitrate systems were selected for radiation measurement with the spectrometer to assess possible suitability for use in an infrared flare composition. The seven additional oxide systems are combinations of the metals boron, silicon, and tantalum with the oxides manganese dioxide, cupric oxide and lead dioxide. None of these systems had desirable burning characteristics. They reported that aluminum-manganese dioxide, aluminum-tungsten oxide, magnesium-cupric oxide, magnesium-manganese dioxide, titanium-cupric oxide, and titanium-manganese dioxide demonstrated uniform burning characteristics. They also reported that, as a group, binary mixtures of aluminum, zirconium, hafnium, titanium, magnesium, boron, and silicon with nitrates of lithium, sodium, potassium, calcium, strontium, silver, barium, and lead were radiometrically disappointing.

About January 1963 the survey of the theoretical thermodynamic properties of reactions was completed. The team reported that chlorates and perchlorates are much more energetic than the comparable oxide systems. Of the fuels, beryllium is the most energetic followed by uranium, hafnium, aluminum, boron, zirconium and silver. The most energetic oxidizer is magnesium perchlorate followed by lithium perchlorate, silver chlorate, sodium chlorate, and potassium perchlorate down through cesium perchlorate of the alkali metals. They examined the experimental behavior of reactions of aluminum, magnesium, titanium, and zirconium with

cobaltic fluoride, ferric fluoride, chromic fluoride, manganous fluoride, nickel fluoride and antimony fluoride. They found these reactions difficult to control and observed that the reactions exhibited low radiative output. The reaction of titanium and barium nitrate exhibited a characteristic emission at a wavelength of about 4.5 $\mu$ m that they associated with nitrous oxide as the source. They also stated that the radiant intensity of the nitrous oxide emission is about equal to the best magnesium-Teflon® reaction in this wavelength band region while being much less at all other wavelengths. From this they concluded that the titanium-barium nitrate reaction might offer a means for managing the spectral distribution within the radiative spectrum.

The study to identify new materials for development of infrared decoys continued at the Armour Research Foundation in 1963 by Mr. Karl Franson, Dr. Katz, Dr. Raison, Mr. Paul Ase and Mr. Robert H. Boes under sponsorship of Mr. Sarnow of the Avionics Laboratory, WPAFB. They surveyed heats of reaction of potential mixtures. They stated that oxides and fluoride systems are better than nitrates and perchlorate and that the aluminum-manganese dioxide mixture seems best for release of energy in the 2 $\mu$ m to 3 $\mu$ m and 3 $\mu$ m to 5 $\mu$ m bandpass regions on a volume basis. About 100 reactions were screened and 35 were studied in detail. Metals considered were aluminum, magnesium, titanium, zirconium, hafnium, and boron. Oxidizers considered were manganese dioxide, cupric oxide, cobaltic oxide, tetrafluoroethylene, ferric oxide, tungsten trioxide, lead dioxide, magnesium perchlorate, cobalt(III) fluoride, silver nitrate, ferric trifluoride, sodium nitrate, lead nitrate, barium nitrate, antimony(III) fluoride, and potassium nitrate.

The study to identify new materials for development of infrared decoys continued at the Armour Research Foundation in 1966 by Mr. Franson, Dr. Katz, Dr. Raison and Mr. Ase under sponsorship of Mr. Sarnow of the Avionics Laboratory, WPAFB. Zirconium-tungsten trioxide, zirconium-cobaltic oxide, zirconium-manganese dioxide, zirconium-ferric oxide, aluminum-manganese dioxide, titanium-manganese dioxide, magnesium-manganese dioxide, magnesium-cupric oxide, and magnesium-Teflon®-tungsten trioxide are some of the new reactions that they studied. The Armour Research Foundation team reported that although some of the properties were better, none is better than magnesium-Teflon®. They tried encapsulation of liquids such as toluene for use as an additive to the magnesium-Teflon® reaction. They also tried hydrocarbons, alcohols, amines, nitroparaffins, hydrazine, boranes, and liquid ammonia as fuels and nitrates, nitrogen oxides, fluorinated hydrocarbons and interhalogens as oxidizers. Some solid-liquid mixtures were considered wherein aluminum, aluminum oxide and magnesium oxide were slurried with methanol and furfuryl alcohol. Chlorine trifluoride and white fuming nitric acid slurried with nitronium perchlorate were used as oxidizers.

In a 1967 report, Dr. Raison of the Armour Research Foundation reported altitude and wind velocity studies under a contract from Lt. Richard J. Sorenson of the Penetration Aids Branch, WPAFB. Using a laboratory scale model of the RR-115 Type III decoy flare, the Armour Research Foundation team studied wind velocity

and altitude effects on flare performance. They concluded that wind velocity and altitude greatly affect the infrared radiative output and that methods must be found to reduce these effects. They also reported that burning time is largely a function of altitude. Not long thereafter, in work supported by now Capt. Sorenson of the Systems Engineering Group at WPAFB, Dr. Raison, Dr. Katz, Mr. Ase and Mr. Franson of the Armour Research Foundation conducted laboratory and flight tests of the RR-115 decoy flare. The RR-80 flare, RR-88 flare and the RR-115 flare were flight qualified and tested at Eglin Air Force Base and NOTS China Lake. Some of the flares were tested at very high altitudes. They collected relative radiative intensity versus Mach number data, which probably was the first time such information was recorded. They conducted Safety Qualification tests of the RR-115 flare at NAD Crane and added another test for parasitic ignition as a result of a Dr. Handler China Lake report in 1968 that impact from 50-caliber projectiles can ignite magnesium-Teflon®-Viton® A compositions. This had never been tried previously with the RR-115 flare. Two flares were rigidly mounted 3-inches apart. The bullet impact into the first decoy did not ignite the second parasitically. As a result of this experiment, they recommended that all future flares be designed to not ignite parasitically and concluded that the RR-115 flare is extremely safe and has excellent radiative properties both in the laboratory and in flight. In addition, they claimed to have a laboratory measurement procedure that realistically simulates the flight test environment with respect to radiative characteristics of the flare.

In the mid-1960s, Dr. Raison and Mr. Ase of the Armour Research Foundation, studied the effects of windstream on the RR-80 flare for Mr. Sarnow of WPAFB. The purpose was to develop a flare that would not be affected by windstream. They added a wire mesh shield in one case and in the other an annular shield with apertures to protect the combustion reaction from the windstream. They reported a 5-fold reduction in the radiative output at Mach 0.3 and more at higher speeds.

Under contract to the Avionics Laboratory of WPAFB in the mid 1970s, Dr. Raison, Paul K. Ase and Dr. Katz of the Armour Research Foundation conducted a high intensity flare investigation. The goal was to develop improved compositions for infrared flares for high performance aircraft operating at supersonic speeds and high altitudes. They needed more radiation in the 1.7 $\mu$ m to 5.5 $\mu$ m bandpass region. They explored additives to create hot particles in the plume. Some of the particles were carbon particles, inorganic oxides, carbonates, and solid hydrocarbons. Tests were performed at 0.6 to 2.0 Mach and at 20,000 to 60,000 feet simulated altitude. Graphite, naphthalene, sodium carbonate and anthracene improved performance substantially. They compared their requirements against the F-4 aircraft at nose and tail and with the Sidewinder 1C missile.

About 1969, Dr. Robert W. Evans, now employed by the Atlantic Research Corporation (ARC-Virginia), a division of Susquehanna Corporation, Alexandria Virginia, reported a study to learn how combustion takes place, the species generated as a gas and as a solid, and how these species emit. In this effort, Dr. Evans identified species that radiate in the infrared and their radiative strength.

Some of the species studied were: hydrogen bromide, hydrogen chloride, hydrogen cyanide, hydrogen fluoride, deuterium fluoride, water, hydroxide radical, deuterated hydroxide radical, cyanide radical, cyanogen, carbon monoxide, carbon dioxide, carbon oxysulfide, nitric oxide, nitrous oxide, and ammonia. He reports that solid carbon is the emitter in the typical decoy magnesium-Teflon® flare.

### **Universal Match Corporation (UMC)**

The Wright Air Development Center at WPAFB started a contract in 1955 with the Universal Match Corporation for research on infrared flares. At that time, Dr. Herbert Ellern was the Staff Scientist, Department of Applied Research, of the Universal Match Corporation in St. Louis Missouri. The contract objective was to develop infrared flares and measurement equipment. They wanted the flares to operate at high altitudes and Mach 1.0 with maximum radiation between 0.75 $\mu$ m and 3 $\mu$ m of the infrared wavelength region. To pursue that objective, the Universal Match Corporation loaded test compositions into M-112 photoflash cartridge cases or M-123 photoflash cartridge cases. They explored 42 different compositions with aluminum, iron, stainless steel, nickel, copper, manganese, charcoal, zirconium and silicon as fuels. The oxidant usually was potassium perchlorate, but barium chromate was also considered. They fired test flares from an A6 Lambert dispenser and used a Leeds and Northrup optical pyrometer to measure temperature. Their goal was for the flare to radiate intensely in the near-infrared with minimum visibility but invisible beyond one-half mile (for covert uses). They evaluated a cool burning composition that consists of 85 parts iron powder (3 $\mu$ m to 5 $\mu$ m particle size), 10 parts potassium perchlorate, 5 parts barium chromate and about 2 parts nitrocellulose. That composition reached a temperature of about 700-800°C. The composition ignites and burns readily at extremely low pressures even though greatly under-balanced in oxygen. They noted that a showering action achieved a greater radiating surface area and that a showering flare was desirable because of the greater surface area that was radiating.

The Universal Match Corporation team also tried a rubber based binder mixture, in parts by weight, of silicon 20 parts, Thiokol LP-2 15 parts, potassium perchlorate 9.7 parts, lead tetraoxide 55 parts, and stearic acid 0.3 parts. The main composition mixture, in parts by weight, is iron powder 83.5 parts, potassium perchlorate 9.5 parts, barium chromate 4.7 parts, vapor phase inhibitor VPI-220 0.1 parts, Sterotex® 0.25 parts and nitrocellulose 2.0 parts. Sterotex® is a fine powder prepared from food grade vegetable oil. The binder mixture is mixed with the main composition in a ratio of 1-part of the binder mixture to 6-parts of the main composition. This composition is pressed into pellets of 0.125 inches in diameter by 1.8 inches long.

Universal Match Corporation investigators also made a prototype of a Roman-Candle type flare package about 1955. These test devices were either pyrotechnically fused or initiated by electric igniters, the latter providing for the possibility of firing the pellets individually. They developed measurement

instruments for test at low temperature and up to 100,000 feet altitude. These instruments did not provide spectra. They recorded radiant energy in the range of 0.75 $\mu$ m to 3.0 $\mu$ m infrared wavelength bandpass. They also measured visible energy to determine the degree of covertness. About that time, Eastman Kodak provided information concerning lead sulfide cells. They said that cooling with ice and water to 0 °C was not necessary since chopping at 3000 hertz eliminated temperature sensitivity of the lead sulfide cells to a great extent. To enable test result comparisons with Picatinny Arsenal and Johns Hopkins Radiation Laboratory, data were presented in kilowatts per second per gram of composition.

As reported in a 1957 report, the Universal Match Corporation was engaged in an effort to reduce the weight of the Flare Ejector RR-78/ALE, believed to be the RITA flare battery dispenser, and to adjust and control the ejection velocity of flare pellets for protection of a B-47 bomber at 75,000 feet flying at Mach 2.5. To overcome ignition failures of the RITA flare, the ignition material was changed to 90 parts by weight of barium chromate, 10 parts boron, and 5 parts nitrocellulose. In addition they added silicon, infusorial earth, ground glass, and fine sand to form an ash from the burned combustion products of the ignition composition in order to retain the heat on the surface of flare composition. Even when the flare size was doubled, the radiative power of the RITA flare was insufficient to protect the B-47 bomber. Evaluation of the RITA flare, with Dr. Herbert Ellern as principal investigator, was ongoing in 1957.

Between 1956 and 1959, the Universal Match Corporation had a contract with the Wright Air Development Center of WPAFB for airborne infrared countermeasures. Originally the work was concerned with dispersal of low-visibility pyrotechnic mixtures. Even at that early date, researchers and operational personnel recognized the benefits of a low-visibility decoy. This goal later was abandoned as being too difficult to achieve adequate radiated levels of energy in the required wavelength band. The focus of the effort was changed to the adaptation of conventional white light producing flare compositions of the so-called RITA type. They reported being able to achieve high levels of infrared radiation in the desired spectral regions from compressed cylindrical pellets burning on all surfaces. Additional objectives were to develop showering type, low intensity, and flares that radiated in the long wavelength region. They experienced operational problems of ejecting substantial numbers of these pellets and sequentially igniting them under flight conditions from B-47 bombers at altitudes to 45,000 feet.

Next, the effort was directed toward the development of flare compositions of a new type that produced considerably higher levels of infrared radiation. The intent was to use the improved composition to replace the illuminating composition in the RITA flare. Operational problems continued. To overcome these deficiencies, they initiated general and theoretical studies to understand the reaction mechanisms of conventional metal-oxidizer combinations of various stoichiometries. One approach was to replace the magnesium with another fuel but continuing with sodium nitrate as the oxidizer. They considered fuels like aluminum, boron, beryllium, carbon,

chromium, iron, magnesium, molybdenum, silicon, thorium, titanium, tungsten and zirconium. They computed the major thermodynamic properties of these reactions. They repeated the experiment with lithium nitrate as the oxidizer in place of the sodium nitrate. Many of the candidate fuels were ruled out for reasons of toxicity, safety, and practicality. The study was narrowed to aluminum, magnesium, and zirconium as the fuels and sodium and lithium nitrates as the oxidizer, and in some instances, they used both magnesium and aluminum in the same formula. These fuel/oxidizer combinations were also evaluated by calorimetry.

As an alternate manufacturing process, the Universal Match Corporation explored casting the RITA composition using various binders as the casting agent. These compositions also did not produce sufficient radiation. Next they considered casting thermite type compositions. One shape was spherical with internal burning to produce sufficient pressure for combustion propagation and with holes on the exterior surface to allow the combustion products to exit. One should note that the Universal Match Corporation team already had been considering the Balls-of-Fire concept that has many similarities to this approach. This approach also fell short of the desired infrared output. About 1956, news and information about the high infrared output of magnesium-halogenated hydrocarbon compositions was propagating rapidly throughout the flare industry. With this information, the Universal Match Corporation team chose to abandon the cast composition investigations and to continue development using the new magnesium-halogenated hydrocarbon compositions technology.

The Universal Match Corporation team reported the RITA flare excelled in only the visible portion of the spectrum. Instead of the illuminating composition, they next explored magnesium, Teflon® and Kel-F® wax as the main composition that they reported to be better than the RITA output. A magnesium-Teflon® composition, named FLORA, was reported to be 18 times better in the 2µm to 3µm bandpass region and five times better in the 3µm to 5µm bandpass region as compared to the magnesium-sodium nitrate composition in the RITA flare.

Continuing in 1958, the Universal Match Corporation team reported that FLORA flares with a composition consisting of 54% magnesium (22µm particle size) and 46% Teflon®-7X had a tendency to snuff out at high altitude. They added titanium in one case and boron/barium chromate in the second case to facilitate combustion. FLORA Type B composition consists of 42% magnesium, 49.2% Teflon® and 8.8% boron-barium chromate mixture. FLORA Type C composition consists of 39.9% magnesium, 46.8% Teflon® and 13.3% boron-barium chromate mixture. A 60% magnesium-40% Teflon® composition worked well as did the one with 8.8% boron/barium chromate added to the mixture. The latter is a mixture of 16% boron with 84% barium chromate. The FLORA flares are cylindrical, weigh about 3.4 pounds (1545 grams), occupy 54.75 cubic inches and have an 80.22 square inch surface area. Burning is over the entire surface.

Another approach is to paint the external flare surfaces with a 16% boron - 84% barium chromate mixture to facilitate burning at high altitude and high ejection speed. Substitution of calcium chromate for barium chromate that releases much more energy was also considered. To facilitate combustion when loaded into an RR-77 flare assembly, they added titanium in the one case and the boron-barium chromate mixture in the other case. Both the titanium and the boron-barium chromate mixture when added to the magnesium/Teflon® mixture radiated substantially more than did the RITA-1A flare when tested at 50,000 feet altitude. Flares with the mixture of 8.8% boron-barium chromate added to a 60% magnesium-40% Teflon® mixture were reported to burn 4.8 seconds, which was considered too fast. To obtain additional data about the experimental units, ten different flares that would fit the RR-77 flare assembly block were developed that were sent to Aerojet-General for simulated altitude and wind-tunnel tests using the vacuum chamber facilities there.

To achieve the infrared output required for protection of aircraft with very large radiative signatures, a program was started at the Universal Match Corporation for development of a high-energy producing device. A requirement was set for 20 kW/sr in the 1.8 $\mu$ m to 2.8 $\mu$ m bandpass region and 35 kW/sr in the 3.0 $\mu$ m to 5.5 $\mu$ m bandpass region. The flare size had to be such that a minimum of four devices would fit into an RR-77 flare assembly block of the AN/ALE-14 dispenser system. They prepared cylindrically shaped pellets of 4.375 inches in diameter by 3.5 inches long. The pellets weigh about 3.3 pounds (1500 grams). Their surface area was about 80.2 square inches, the entire surface area of which would be ignited at one time. Two pellets were placed into each of the two five-inch diameter flare ejector tubes of the flare assembly block. After one such set-up was fired successfully, a second was sent to the Wright Air Development Center at WPAFB for further testing.

On 19 September 1958, Universal Match Corporation put a 1000 cubic foot vacuum chamber into operation to support the decoy flare research. It could be evacuated to 500  $\mu$ m of mercury and could simulate 100,000-foot altitude.

## Great Britain (UK)

In the late 1950s, Wallop Industries Ltd. received a contract from the Royal Armament Research and Development Establishment (RARDE) Langhurst Horsham West Sussex UK to develop tracking flares. These contained illuminating composition, an example of which is SR-568A made from 55 parts magnesium, 4 parts lithographic varnish and 41 parts sodium nitrate. This is the formula utilized in flare number 2. The number 2 flare is called FIRESTREAK, the number 3 flare is called SEASLUG, the number 4 flare is called RED DARTER, and the number 5 flare is called RED SHOES. The flares are different in length and contain illumination composition variants.

Infrared decoy flare development spread quickly to the UK from the USA. In September 1957, Mr. T. S. Moss, Mr. D. R. Brown, Mr. T. D. F. Hawkins of the Royal Aircraft Establishment (RAE) Farnborough, Hants England evaluated three compositions for possible use as an infrared decoy. These were: SR-580, SR-107 and Cordite Type SC.

a. SR-580, an illuminating formula, is 60% magnesium and 36% sodium nitrate, and 4% acaroid resin.

b. SR-107 is 35% magnesium and 65% ferric oxide.

c. Cordite SC is 49.5% nitrocellulose, 41.5% nitroglycerine, and 9% carbamite. Synonyms for carbamite are: 1,3-diethyl-1,3-diphenylurea, bis(N-ethyl-N-phenyl)urea, N,N'-diethyl-N,N'-diphenylurea, centralite, and ethyl centralite.

The materials were evaluated in the wavelength bands in which lead-sulfide and lead-telluride are sensitive. Although the cordite spectrum showed a strong emission in the region of the red spike (carbon dioxide emission region), the RAE team speculated that this material would not radiate sufficiently at high altitude. Their recommendation was that RARDE Langhurst should continue studying selective emitters and to exploit Kel-F® material, which was reported in America to be a very efficient decoy material with a low burning temperature of about 1700 °C.

About 1959, Mr. Brown, Mr. J. P. Chamberlain, Mr. N. D. P. Hughes and Mrs. Shirley Jenkins of the Royal Aircraft Establishment Farnborough, installed a radiometer spectrometer inside a 1959 Hawker Siddeley Comet 2E aircraft. The spectrometer line-of-sight was through the side of the fuselage. Pressurization was maintained inside the cabin. The gear was capable up to 14,000 meters altitude. They made measurements in the infrared 2µm to 5µm bandpass region. Simultaneous clusters of magnesium-sodium nitrate illumination flares showed that the infrared output was proportional to the flame area and that the infrared emission more than doubled by increasing from four flares to six flares in a cluster.

Mr. Hughes, Mrs. Jenkins and Mr. Brown of the Royal Aircraft Establishment Farnborough conducted airborne emission measurements of infrared decoy flares in 1962. Radiometers operating in the 2 $\mu$ m to 3 $\mu$ m and 3 $\mu$ m to 5 $\mu$ m bandpass regions were installed in a Royal Air Force (RAF) De Havilland Comet-2 XN453 aircraft. The radiometer could be operated while the inside of the instrument was pressurized. The instrument was capable of operation up to 14,000 meters (45,934 feet) altitude.

RARDE Langhurst made the prototype flares for the experiment. The infrared flares were intended to protect "V" bombers. The term "V" bomber was used for RAF aircraft during the 1950s and 1960s that comprised the UK's strategic force, namely the Vickers Valiant, the Handley Page Victor and the Avro Vulcan. The flare decoy units identified as Flare Type E/2/1, later to become the UK Mk 1 Decoy about March 1963, were 2.25 inches in diameter by 5.3 inches long. The units contained a safe and arming device (S&A). The grain contained 55% magnesium and 45% Teflon® with longitudinal grooves around the grain circumference and produced a rise time to peak intensity of 0.5 seconds. The radiative output of these decoys was measured at 1,000, 10,000, and 40,000 feet altitude. They concluded they needed to drop pairs at low altitude and quadruples at high altitude.

Mr. Jackie Roberts, about 1963, fabricated an infrared spectrometer for the Vulcan aircraft.

## COMPOSITION CHARACTERIZATION and CONCEPT DEVELOPMENT

### Forward Launched Decoy

The Forward Launched Decoy (FLD) concept was first noted during the Balls of Fire project about 1958. During a decoy trajectory study for the Aeronautical Systems Division of WPAFB, Mr. J. H. Henson of the University of Texas revived the concept in 1961. Mr. Henson's objective was to convert the AN/ALE-9 chaff rocket, developed by the Defense Research Laboratory in 1954-1959, to forward launch an infrared decoy flare. He replaced the chaff with cylindrical pellets pressed with a 60% magnesium- 40% Teflon® composition. The combustion products from the flare were exhausted through ports in the head of the device. Universal Match Corporation and the Armour Research Foundation provided flare pellets for this project.

As follow-on to this work, in early 1960, Mr. Sarnow of WPAFB sponsored the development of the RR-96(XY-1)/AI infrared countermeasures rocket flare at the Armour Research Foundation of the Illinois Institute of Technology, the principal investigators being Dr. Raison and Dr. Katz. The assembly contains an RR-80 flare. The rocket is 43 inches long by 2.75 inches in diameter and weighs a total of 12.9 pounds. The rocket is dispensed from an ALE-9 type dispenser system from B-47 and B-52 aircraft. They conducted sled tests at Edwards Air Force Base, safety tests at NAD Crane and flight tests at Eglin Air Force Base. When subjected to a 1000 feet per second velocity during a 12 second static burn, the Armour Research Foundation team reported that the radiation in the lead sulfide and lead telluride bands had enough energy to serve as a countermeasure to protect B-47 and B-52 aircraft.

About 1960, Mr. R. Stern of the American Machine & Foundry Company, Niles, Illinois, under a contract with the Wright Air Development Center of WPAFB worked on a concept for a forced trajectory decoy rocket. Mr. Stern evaluated parameters such as the trajectory needed by the decoy to defeat the threat, control, propulsion and stability requirements. This may have been a follow-on project to the study by Dr. Katz of the Armour Research Foundation at the Illinois Institute of Technology in 1958 of the concept of using the Balls of Fire in a forward launched device, especially to protect bombers.

Mr. Knapp and Mr. Arthur Graff of the Research Laboratories at Picatinny Arsenal continued forward launched decoy flare development efforts under sponsorship of Mr. Francis Linton of the Avionics Laboratory at WPAFB as described in a 1964 report. The objective is to determine feasibility of using pyrotechnic flares to simulate the total radiation characteristics of various rockets such as the High Velocity Aircraft Rocket (HVAR) in the 2 $\mu$ m to 5 $\mu$ m spectral bandpass region. They wanted a forward launched infrared decoy for supersonic vehicles such as the B-70

bomber. Rocket propelled flares appeared feasible using a magnesium-Teflon® composition. They needed very high radiant output from the flare for 20 seconds at 70,000-foot altitude. The Picatinny Arsenal team formulated an ignition composition FW-210 consisting of manganese dioxide and zirconium that is effective at high and low altitudes and they performed wind tunnel and altitude chamber tests to support their investigations. The perforated-can flare concept (related to the shielded flare concept) was also considered for incorporation into a forward launched decoy flare design.

Between 1963 and 1965, Mr. Henson, Mr. J. Worden, and Mr. Richard T. Balzen of Tracor, Austin Texas developed the XADR-9A countermeasures rocket. Mr. Eugene E. Hawthorne and Mr. B. W. Putriment of the Air Proving Ground Center, Eglin Air Force Base tested the flare portion of the XADR-9A countermeasures rocket in 1967. The Eglin team also wanted to develop a decoy flare fired forward by a rocket. They observed a loss of radiative power during operational tests and noted that the smoke trail caused significant obscuration, dependant on the observation angle.

### **Roman Candle Flare (RC)**

As early as 1972, the Grumman Aircraft Company received a contract for development of a hydrocarbon fuel infrared decoy also known as the "Roman Candle" (RC) decoy flare. This development is based upon using a flexible shaft such as used in pole-vaulting to hold the decoy or a scaled up weed-burner from 15 to 17 feet below an HH-1K helicopter. The contract evolved into the joint service project reported in 1973. Mr. Breslow of China Lake and Mr. Schivley of WPAFB directed the project whose goal is to investigate and demonstrate the use of on-board fuel from the aircraft to generate infrared decoys. This includes investigation of rapid gelling, gelling additives, the quantity necessary, decoy size, burning duration, ejection velocity, spectrum matching to the aircraft, and rapid cycling of ejection. Both Air Force JP-4 fuel and Navy JP-5 fuel were considered. They reported several observations, these being: (1) the efficiency of Navy JP-5 fuel is higher than that of Air Force JP-4 fuel, (2) the efficiency of both fuels is better in the 3 $\mu$ m to 5 $\mu$ m bandpass region than in the 2 $\mu$ m to 3 $\mu$ m bandpass region, and (3) efficiency increases with decoy weight (size) as does burning duration.

The airborne evaluation of the Roman Candle system using a demonstration model was conducted on a UH-1N helicopter. The concept is applicable to either the preemptive or the reactive mode of countermeasures. The demonstration model weighs 42 pounds and contains 100 decoys. Feasibility was demonstrated. In follow-on flight tests, Roman Candle fireballs were deployed from an A-4 aircraft at 150 to 435 knots and at 3,500 to 20,000 feet altitude. Success was achieved at 435 knots and 7,000 feet altitude or lower and at 200 knots at 20,000 feet altitude. As a further option, they could fire 12 single prepackaged Roman Candle shots from a LAU-61/A Launcher. Later four live fire shots were conducted. The target aircraft was the NA4-E and the chase plane was the NRA-3E equipped with an AIM-9G

Sidewinder surrogate for a threat missile. The test was conducted at 300-345 knots and 3,500 feet altitude.

Airborne infrared measurements of the Roman Candle flare were made during a flight test on 26 August 1977. Mr. Charles. L. Godwin of the Pacific Missile Test Center (PMTTC), Point Mugu California conducted the test. Radiometric and spectral measurements were made with the Airborne Turret Infrared Measurement System (ATIMS) and High Speed Instrumentation Pod (HSIP) pods. The burning duration of the Roman Candle flares was too short. The spectra showed a near graybody distribution of radiation, which suggests incomplete combustion and the formation of soot as the emitter. The Mk 46 Mod 1A flare was used as a reference.

### **Balls of Fire Decoy (BOF)**

On October 25, 1954, Mr. J. L. Hult of the RAND Corporation, Santa Monica California reported the results of their study of infrared countermeasures for the Air Force. This comprehensive study outlined the threats posed, tactics and countermeasure requirements. They considered mechanical and system needs and radiation characteristics, thermodynamics and chemistry of proposed sources. They also considered mixed and multiple expendables, smoke puffs, towed sources, and infrared blinkers. A significant result of this study was the recommendation for a decoy flare concept named the Balls of Fire (BOF). They identified the parametrics of the problem, listed the physical properties of the reaction constituents that included mixtures of aluminum with iron oxide or molybdenum oxide or tungsten oxide.

The Air Force contracted with the Armour Research Foundation to develop the Balls of Fire concept as an infrared decoy to protect B-47, B-52 and B-58 bomber aircraft from infrared missile threats in the 1.8 $\mu$ m to 2.8 $\mu$ m (lead sulfide) bandpass region. Dr. Katz and Dr. Elliott Raisen of the Armour Research Foundation were the principal investigators. Other contributors were Mr. Ase, Mr. Franson, Mr. F. Child, Mr. W.F. Christian, Mr. A.G. Lane, Mr. H. Olson, Mr. J. Pito and Mr. R. Spaulding. The project lasted from about 1956 to 1958. Their concept was to make a four-inch diameter shell containing a thermite composition such as aluminum-tungsten oxide. These burning spherical shells would be dispensed from aircraft to serve as an infrared decoy. Some additional concepts for this device were: an enclosed reaction, a fusible shell, an intumescing shell, a reaction with ejection of combustion products through ports in the shell (perforated-can concept), and impinging flames.

Early Balls of Fire shells were made from graphite, copper or iron. Molybdenum and tantalum shells were also considered. Due to shell ruptures during test, the developmental focus was directed toward shell material, shell wall thickness, thermite charge composition, and insulation evaluations. Additional options for reducing agents in the thermite charge that they considered were aluminum, beryllium, chromium, magnesium, Teflon®, lanthanum, hafnium, scandium, zirconium, lutetium and yttrium. Some oxidizer choices for the thermite were

molybdenum oxide, ferric oxide, nitrogen tetroxide, tetrafluoroethylene, and various nitrates.

In that time period, it was thought improbable that pursuit missiles would home on the exhaust of a B-58 bomber cruising at Mach 2 presumably because the threat would not be able to catch up to the target. As a result of the perceived threat capability, about 1958, Dr. Katz of the Armour Research Foundation proposed the concept of using the Balls of Fire in a forward launched device especially for protection of B-58 bombers. Protection of B-47 and B-52 bombers was also under consideration.

Theoretical calculations by the Armour Research Foundation team suggested that hafnium, scandium, yttrium or lutetium should yield superior systems. The aluminum-tungsten oxide and aluminum-iron III oxide thermites functioned satisfactorily at 75,000 feet simulated altitude. The aluminum-tungsten oxide composition ignites at 840 °C, which is 200 °C above the melting point of aluminum suggesting a liquid-solid reaction. Other formulae did not propagate but did so upon addition of tantalum ribbon or potassium dichromate. Additional developmental tasks included study of accelerators, diluters, and retarders for the aluminum-tungsten oxide formulation. The investigators also planned studies of heats of reaction, burning rates, high altitude effects, and alternative reactions.

A 2-mm thick graphite shell which had 38 seven-sixteenth holes distributed over the sphere surface was tested. During the burn, incandescent particles were ejected through the holes to form a cloud. The spouting of these particles resulted in the device being labeled a "spoutnik". Perhaps this is a play on the word Sputnik, it having been launched on October 4, 1957. The plan was to launch these decoys in a forward direction suggesting that even at that early date, dispenser location and ejection direction were known to be important factors for defeating some threats.

Another concept, the transient shell system, is a variant of the above graphite shell. Instead, the Armour Research Foundation team used a phenolic shell that would burn away during the functioning of the device. They note that the shell is necessary to prevent dispersion of the reaction products, but after the gasses have vented, the shell is no longer needed. Removal of the shell exposes the infrared radiator, that being an incandescent coherent sphere clinker of tungsten sponge resulting from the burning aluminum-tungsten oxide thermite.

The Armour Research Foundation researchers lacked radiation measurement equipment in the 1958 timeframe. They tried to use the Barnes radiometer at the Universal Match Corporation's test location in Saint Louis Missouri. It did not have sufficient capability and would overload during test. The researchers then obtained a radiometer with a lead sulfide cell and filter from Johns Hopkins University. Radiometric performance and combustion temperature were measured, the latter between 2000 K and 3000 K.

The Balls of Fire concept was revived about 1961 during the development of the RR-88(XY-1)ALE Flare for the B-52 bomber. The dispenser concept contains two ejection tubes. Each tube has two BOF flares encapsulated with polyurethane foam in a metal capsule. Each Balls of Fire flare, which is compatible with the B-52 AN/ALE-14 Ejector System, is ejected individually downward at 65 to 150 feet per second. The flare burns for about 10 seconds with a temperature of 2200 K to 3000 K. The composition in these Balls of Fire flares is a mixture of 22.5% aluminum, 76.5% tungsten oxide and 1% Teflon®. The ignition composition is a mixture of 57% barium chromate, 38% zirconium, and 5% nitrocellulose.

The Balls of Fire decoy flare development ultimately was not adopted, however the concept was to be revived again about 1966 using improved materials. An expanded discussion of the Balls of Fire project may be found in *Electronic Countermeasures*, in Chapter 22 written by Dr. Marshall D. Earle.<sup>10</sup>

### **RITA-FLORA Flare Developments**

The RITA-FLORA flares make up a family of flares developed by Picatinny Arsenal for the Air Force for protection of the B-52 bomber. Their contents evolved from an illuminating composition to one that radiates in the infrared. The RITA-FLORA developmental evolutions lead to the development of the ALA-17 MTV flare.

At the request of the Air Force, Mr. Stanley Resnick, Mr. Gary Weingarten, Mr. Knapp, Mr. Leo Frey and Mr. Jesse Tyroler of Picatinny Arsenal started development of a RITA flare in October 1954. The flares were to be dispensed from a Lambert A-6 Ejector that was designed to dispense M-112 photoflash cartridges these being 1.57 inches in diameter by 7.73 inches long. The burning time was to be 3 seconds while radiating intensely in the 0.8 $\mu$ m to 2.5 $\mu$ m bandpass region. The composition in the RITA flare, in parts by weight, is 70 parts magnesium, 30 parts sodium nitrate and 5 parts Laminac® 4116 (a polyester binder). It burns 4.5 seconds statically and 2.5 seconds dynamically when ejected at 50 to 100 feet per second. There were problems with the black powder expelling charge. A composition, in parts by weight, of 10 parts boron, 90 parts barium chromate and 5 parts nitrocellulose was added for ignition of the first fire. 1000 units were delivered to the Air Force by May 1955.

### **Mini-Flare Development**

In November 1967, Picatinny Arsenal was requested by the Electronics Command at Fort Monmouth to develop a mini-flare for a dispenser, which the Electronics Command had developed. The nomenclature assigned is believed to be the XM-126 dispenser. The dispenser designed for the UH-1D helicopter carries 154 mini-flares. There are two dispensers per aircraft. The flare is 1-inch in diameter by 2.75

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<sup>10</sup> *Electronic Countermeasures*, Peninsula Publishing, Los Altos California, 1978, ISBN 0-932146-00-7.

inches long and weighs 0.16 pounds. The Navy wanted to adapt this flare to their helicopters and FAC aircraft but the Army developed flare was not bore-safe. A feature of the dispenser design is that if a flare does not ignite, photodiodes in the dispenser will cause another flare to be fired immediately. The Navy at China Lake undertook the task to develop a bore-safe device. In addition, China Lake proposed two alternate concepts. One is a towed decoy and the other is a smoke/flame blob. It was anticipated that a suitable towed flare could be produced that would provide on/off capability and long duration. The system would consist of appropriate cockpit controls, fuel supply of the aircraft, fuel line to the flare burner, the burner and flight control units. Such a system would be inexpensive when compared to a flare dispenser and multiple flares. The system would not require ignition until needed. The second approach consists of expelling either a flaming blob or alternatively an absorbing cloud from the aircraft. This approach also offers the advantages of utilizing the aircraft's existing fuel supply. Both require a pumping or ejection system and ignition source. The ignition source could be excluded if the primary fuel is mixed with a small amount of pyrophoric material, which would cause the combined mix to burn when introduced into the atmosphere. These concepts no doubt are the precursor to the Roman Candle flare development. The concepts were expanded to provide an independent feed control of pyrotechnic powders to provide additional degrees of freedom of burning rate, fuel to oxidizer ratio, variable intensity with altitude, on/off, and restart. Solids considered were magnesium-Teflon® and magnesium- sodium nitrate.

In a 1971 report, China Lake noted that it successfully made a bore-safe design for the mini-flare dispenser and was evaluating the dispenser for Navy helicopters and FAC aircraft. The ignition system was adapted from the EX 49 Mod 0 decoy flare. The expelling charge was replaced by a Mk 2 Mod 0 ignition element that when fired initiates a pellet of ignition mix CT-144, which had been placed in the piston cap. The bore-safe mini-flare grain consists of composition PL 6320. The grain is 1.88 inches long by 0.94 inches in diameter and weighs 0.066 pounds.

In 1970 Mr. Breymaier headed up a team at the Willow Run Laboratories of the University of Michigan to evaluate mini-flares for low speed aircraft against ground-launched infrared seeking missiles, one of which is the Chaparral 1C missile. The team studied launch zones, flare trajectories, aircraft speeds and flare rise-times. Mr. Knapp was part of a team at Picatinny Arsenal that developed the mini-flares in several configurations. The flare is 1-inch in diameter by 2.75 inches long and weighs 0.16 pounds. By 1972, the Picatinny Arsenal team reported that a small, high-energy, rapid ignition flare had been developed to provide protection for the AH-1, UH-1, OH-58 and OH-6 rotary wing aircraft against ground-launched missiles such as the Redeye, Sidewinder and Chaparral missiles. The Picatinny Arsenal team tested flare compositions under various wind conditions. They added nitrocellulose, anthracene, Viton® A, Viton® B, manganese dioxide, zirconium, molybdenum trioxide and chromium trioxide to the magnesium-Teflon® basic composition. The flight tests were at China Lake sponsored by the Electronics Command at Fort Monmouth. The Army Missile Command Redstone made

dynamic measurements of the Mk 46 Mod 1 flare and the XM-196 mini-flare. The drop altitude was 1,500 feet. The flare radiant intensity was measured from the ground. The mini-flare had a good rise time in a 100-knot air stream but burned less than 3 seconds. The Mk 46 Mod 1 flare also had a good rise time but did not sustain intensity. At 400 knots, the Mk 46 Mod 1 flare had a very poor rise time. The altitude was 5800 feet for the latter test.

## **Flare and Decoy Developments and Improvements**

This section shows a number of tasks in approximate chronological order. The descriptions are intended to show that improvement of the decoy flare is a continuous process, that many tasks are ongoing at one time, and that many activities are simultaneously involved in this effort. There always is the need to make the product perform better, to redesign the product to make the device safer or less hazardous or just to incorporate a new feature because the threat that it has to defeat has changed. This section is also intended to describe new and different technology as it is applied to devices undergoing development or product improvement.

The need for infrared decoys was not limited to the U. S. Navy. The U. S. Air Force, U. S. Army, and Great Britain initiated studies and developments as soon as the infrared missile threat appeared. Others worldwide immediately started their own programs. One example of this is the infrared countermeasures study under contract to the Air Force, reported in 1953, by researchers of Haller, Raymond and Brown-Singer Inc., State College, Pennsylvania. The concern was protection of bombers at high altitude. They concluded the two most promising methods to protect bombers were decoys and signature reduction. Their study included pyrotechnic agents, chemical smoke, radiant particles, ejected decoys including multiples and towed decoys. Cooling and shielding were considered for aircraft signature reduction.

From January 1949 to January 1960, Del Mar Laboratories, Santa Monica, California conducted research on an infrared aerial towed decoy system. They used a ram-air turbine and an alternator to provide an electrically heated infrared source in the towed vehicle that radiated through a Pyrex® dome (transmission is about 0.3 $\mu$ m to 2.5 $\mu$ m) that passes infrared radiation in the lead sulfide wavelength bandpass. In 1956, Del Mar made three flyable towed systems for towing behind high-speed bombers. These were tested successfully. In 1958, two infrared towed targets were flight tested at the Naval Air Test Center, Patuxent River, Maryland: one from Del Mar Engineering Laboratories and the other from the Colonial Aircraft Corporation. The target that was stable in flight while being towed had four tail fins and rotated at 1000 rpm. Four tubes adjacent to the fins housed unidentified flares. The target was designated CT-2 target and is similar to the Aero 36 target. The CT-2 target spins at 4-times the rate of the Aero 36 target and weighs 49 pounds as compared to 19 pounds for the Aero 36 target. The Colonial Aircraft Corporation

unit, while undergoing test at 250 knots, spun at a high rate and completely disintegrated.

From 1954 to 1956, Dr. Earle while employed at the Johns Hopkins University, Carlyle Barton Laboratory (Radiation Laboratory) conducted research for the Air Force in the areas of infrared decoys, infrared properties of smokes and fogs and the description of infrared target seekers. He measured infrared flares made by Kilgore, then in Westerville Ohio and one flare from Unexcelled Chemical Company of Cranbury, New Jersey. The Kilgore flare named type DF contained potassium nitrate, charcoal and rosin. A variant contained silicates that were added to the DF mixture. Other variants were magnesium, strontium nitrate, potassium perchlorate, sulfur, potassium nitrate, lithium carbonate, and charcoal added to the DF mixture. Dr. Earle noted that flare compositions containing charcoal have the lowest energy content. He also considered reflective decoys such as smoke puffs to scatter light and suggested a gelled hydrocarbon such as napalm with an oxidant. As follow-on, he gelled gasoline, kerosene, benzene, toluene and xylene. The gasoline and kerosene gels yielded enhanced carbon dioxide emission. He noted that fire clay and silicon carbide additives did little to alter the infrared spectrum and concluded that reflective decoys would be of little use. Nevertheless, smokes, fogs and low-density plastics were considered for their ability to obscure or reduce the radiative signature of aircraft. Dr. Earle also proposed an infrared-radar decoy that lasted 15 minutes and would emit radiant energy one-quarter of that of the B-47 bomber. The radar part would be an aluminum coat on a Mylar parachute. He also discussed the features of a low-temperature infrared decoy and a towed decoy. In his analysis of flare burning time and aircraft protection, he makes the statement that a countermeasure source burning time of 8 to 12 seconds at an intensity, which is dominant over the aircraft, seems adequate.

Mr. J. B. Newman at Johns Hopkins University conducted a study for the Air Force in 1955 concerning pyrotechnic decoys for use as infrared countermeasures. The primary aircraft of concern was the B-47 bomber. The possible missile threats were the Sidewinder, infrared Falcon, Aerowolf, and the British Bluejay, all with lead sulfide detectors. Mr. Newman's team consulted with the Pyrotechnics Group at NOL White Oak, the Infrared Section of Squier Laboratory of the Signal Corps, the Night Photo Laboratory of WPAFB, the Armaments Laboratory of WPAFB and Picatinny Arsenal. Fifteen different types of flares were tested. Six were from Aerial Products, Elkton, Maryland. Four conventional military flares were from Unexcelled Chemical Corp. and three were from Kilgore Corp. The M8A1 and the M26A1 are aircraft parachute flares, the M50 is a tow target flare and the M76 is an airport flare. They took spectra with a Perkin Elmer Model 99 monochrometer using a thermocouple detector. The Leeds and Northrup thermocouple served as a total radiation monitor. Early spectral data were taken at Camp Wometo in Bel Air, Maryland and later spectral data were taken at Edwards Air Force Base, California. The Kilgore K2 flare was declared to be the best of the lot.

In a related effort, researchers at the Johns Hopkins University Radiation Laboratory in the 1956 time period were tasked, as a first priority, to obtain radiation characteristics of targets and decoys. Their second priority was to develop attenuating media. About 1960, Ms. Betty Lou Raskin of the Radiation Laboratory with the advice of Dr. Earle, conducted a study for the Air Force to propose new infrared compositions. The study was prompted by the need for more efficient flares to protect supersonic aircraft that would be developed subsequent to the B-47 bomber and the B-52 bomber. They recognized that the spectral and spatial distributions of the radiation emitted by future aircraft would be different from existing ones. They anticipated that future aircraft would emit much larger amounts of thermal radiation from the engine exhausts and also would radiate due to aerodynamic heating of the aircraft surfaces. The new compositions would need to perform effectively at 70,000 feet altitude where the atmospheric pressure is only about 0.04 times its sea level value and the oxygen content approaches zero. Noting that the FLORA type flare containing mainly magnesium and Teflon®, was a better source of infrared radiation than other types of flares, they set out to explore the reactions of 13 different metals with 17 different highly fluorinated, chlorinated, and oxygenated organic compounds. The Johns Hopkins University team noted that fluorine is the most powerful oxidizing agent and consequently that fluorine atoms should be the sole oxidant present in an infrared flare. They also reported that magnesium was the most practical metal found to be present most often in reactions with the highest theoretical thermal outputs.

The Hayes Corporation, Birmingham, Alabama initiated infrared countermeasures and radiation suppression studies in 1955. During that timeframe it already was apparent that a very strong aircraft infrared signature made it very difficult for decoys to seduce the infrared threat missile from the target aircraft.

There was a need about 1957 to create a decoy device that would simulate the signature of a turbojet engine. Instead of the pyrotechnic decoy flare approach, Northrop Aircraft, Inc., Hawthorne, Nevada proposed an inflatable envelope that absorbs the energy from a self-contained pyrotechnic and re-radiates this energy at a lower temperature approximating that of the heated surfaces of the turbojet engine. Use of an inflatable envelope permits the decoy to occupy only a small volume before being ejected. The low total radiation per unit area of surface dictates the use of a decoy with a large surface area. By use of a large inhibited flare with a long burning time, the inflated envelope decoy could be used as a free or towed target. The resultant decoy would be a large-area extended-source with a low effective temperature.

In a 1957 report, Mr. A. L. Pittinger describes an attempt to make a low-gas tracking flare utilizing an unspecified metal-metal oxide thermite reaction to put inside the Pogo-Hi Rocket nose cone. The reaction releases about 75 joules/gram of energy in the lead-sulfide sensor band region and lasts for 120 seconds. In June 1956 the Cooper Development Corporation (CDC), Monrovia California prepared the first units, the CDC Model 155 infrared emitter. The final model was placed in the Pogo-

Hi rocket target. When the rocket reaches altitude at 60,000 feet, a parachute deploys, the ignited thermite melts the magnesium nose cone that exposes the infrared radiator used to attract a test missile. Radiative output at altitude is about 25% of that at sea level. Another variant was fitted to an F6F-5K drone aircraft with six emitters, two on each wing tip and two on the tail.

Researchers at Ohio State University, during 1955-1956, under contract from the Rome Air Development Center, Griffiss Air Force Base studied infrared emission from flames of methane-air, methane-air with chlorine added, methane-air with a Welsbach mantle added, propane-air, oxygen-acetylene, hydrogen-chlorine, ammonia-oxygen, carbon monoxide-oxygen, methane-nitrous oxide-hydrogen, carbon monoxide-oxygen-sulfur hexafluoride, carbon monoxide-air-Freon 13, and carbon monoxide-air-boron trifluoride. They also studied fuel-air flames with gasoline, paraffin, benzene, aniline, methanol, ethanol, ethyl ether, carbon disulfide and hydrogen as fuels. They attempted to determine the identity of the radiating species, the brightness temperature of the flame and the flame thickness.

In 1956 the Hallicrafters Company, Chicago reported development of flare dispensing equipment under an Air Force contract. They referred to a loaded dispenser case full of flares as a flare battery. The concept is to replace an entire empty or partially filled flare battery with a flare battery containing a full load of flares. The flare battery with a full flare load weighs about 100 pounds. The flare battery has outside dimensions of 6.5 inches by 13 inches by 13 inches. The dispenser case or block has 17 cylindrical cavities, 1.875 inches inside diameter by 20 inches deep. Five flares are placed into each cavity. Provision through the side of the cylinder at five locations along the cylinder length is made for a squib to ignite each individual flare. The dispenser setup can fire each flare at intervals of 0.7 to 10 seconds. There are 85 circuits from the flare battery to the dispenser controller.

Five 2-inch long jacketed-variant RITA Flares, housed in a perforated steel jacket, are placed in each cylinder of the flare battery making a full load of 85 flares. The perforated case design suggests similarity to the Balls of Fire or perforated can design described elsewhere wherein the flame spews simultaneously from all the holes in the surface of the flare case. Besides the RITA flare, additional flares were tested at 50,000 feet and at Mach 0.85 using the flare battery dispenser. The 3-second version is called RITA 3-second variant and a 5-second version is called RITA 5-second variant, both provided by Picatinny Arsenal. Universal Match Corporation provided the UMC-ASC129 flare modified for high altitude and a UMC pelleted flare. Mentioned in 1956 report.

An early 1958 concept was presented to Mr. Francis Linton of WPAFB by Lambert Engineering Company Saint Louis, Missouri for a number of different flare assemblies to improve the RR-77 AN/ALE-14 flare assembly. The RR-77 flare assembly housing fits into the AN/ALE-14 ejector system installed in bomber aircraft. Lambert Engineering offered variations in the number of tubes and the number of flares in each tube. The M-112 photoflash cartridge case was used as

the test vehicle. The flares in the cartridge are ejected sequentially. RITA flare technology utilizing infrared compositions was used for this development.

It was reported in 1959 that Mr. Eugene E. Elzufon of the US Flare Division of the Atlantic Research Corporation had a contract to conduct infrared experiments. He performed controlled burning studies, explored thermodynamics and chemistry of the reactions and conducted high altitude (70,000 feet) burning rate and pressure studies. He also attempted to find binders to replace Kel-F® wax. At that time, the ignition composition was a mixture of 10% boron and 90% barium chromate. The composition ingredients were mixed in a muller and pressed at 400-500 psi. The W137 tracking flare most likely resulted from this work.

Under the direction of Mr. N. C. Eckert, Head of the Research and Development at the US Flare Division of the Atlantic Research Corporation, Mr. H. E. Curtis and Mr. D. D. Parish received funding about 1960 from Detachment 4, Wright Air Development Division of Eglin Air Force Base to develop a long wavelength flare with increased emission in the 3 $\mu$ m to 5 $\mu$ m bandpass region. The researchers primarily investigated fuel and oxidizer additives to the magnesium-Teflon® system. The additives included silicon, anthracene and lithium perchlorate as emitters or as radiation enhancers. As agents to minimize altitude attenuation, they chose nitrocellulose and the boron-barium chromate mixture. They evaluated polyethylene, polysulfides, silicones and epoxies as a combination binder-carbon source-dispersant. Since the efficiency of thermite as a radiating source is less than 10 percent of the magnesium-Teflon®-Kel-F® wax composition, they concluded thermite did not justify further investigation. Performance of the experimental compositions was compared to the USAF TAU-15/B decoy flare whose standard composition is 54% magnesium gran 15, 30% Teflon® #1 and 16% Kel-F® #40 wax. The US Flare Division team did not report any significant technological advancement except for a minor energy per gram improvement with addition of 5% anthracene. In this work, the anthracene was added to increase the amount of hot carbon particles as a combustion product known to radiate as a high emissivity greybody radiator.

In an effort to reduce the radiative signature of missiles, about 1960 Mr. Breslow and Mr. Richard A. Breitengross of NOTS added an unspecified alkali metal salt to the Sidewinder 1-C propellant grain to suppress the booster radiation. They reported a dramatic reduction in the plume radiation.

Mr. David A. Merrell of the Hughes Aircraft Company Infrared Laboratories conducted an extensive study of the feasibility of a modulated pyrotechnic flare about 1960. These experiments lead to development of an electric modulated flare using an incandescent filament instead of a pyrotechnic source. The latter produced an output of about 14 W/sr in the 2 $\mu$ m to 2.5 $\mu$ m bandpass region with an electric input of 475 W.

About 1960, the Geophysics Research Directorate of the Air Force Cambridge Research Center and the Weapons Guidance Laboratory of WPAFB supported work at Block Associates Inc., Cambridge Massachusetts for infrared filtering of the magnesium flare. Mr. Myron J. Block and Mr. Merle J. Persky proposed to change the spectrum of an MTV flare to match that of an aircraft by surrounding the flame with a three-inch diameter filter envelope to remove undesirable wavelengths. To protect the filter envelope, they introduced a coaxial stream of air at 150 miles per hour between the flame and the envelope. In laboratory experiments, they showed the envelope could be protected. They used a Pyrex® tube around the RITA flare and also explored a Corning 7-56 filter.

In 1960, Dr. Hal Waite and Mr. M. Bressler of Aerojet-General reported developments in infrared chemical sources. They reported that carbon particles are a unique source of the observed radiation. To improve the output, they added anthracene to get more carbon products and noted that at altitude, compositions containing anthracene exhibited better performance during the burn when the nozzle was restricted as compared to unrestricted burns.

In a late 1960 report for the Targets Development Laboratory of Eglin Air Force Base, Mr. L. K. Lantz, Mr. R. Hopkins and Dr. Waite of Aerojet-General conducted tasks to fabricate infrared decoy flares for ground and air tests. The prime requirements were good altitude performance and large amounts of radiation in the 3.0 $\mu$ m to 4.5 $\mu$ m bandpass region. They claim the sensitivity of the magnesium-Teflon® reaction to changes in pressure has been reduced by the use of an Aerojet-General developed, blending process that provides utmost homogeneity with the result that there is no change in the burning time from sea level to 40,000 feet and only minor changes to 60,000 feet. Earlier work by Aerojet-General showed that 5 percent incorporation of anthracene enhances the radiation of the basic composition without degradation of its altitude performance. When using this additive, the Aerojet-General team reported energy increases of 8 percent in the 1.8 $\mu$ m to 2.8 $\mu$ m bandpass region and 25 percent in the 3.0 $\mu$ m to 5.0 $\mu$ m bandpass region. The static and airborne test flares, type unspecified, are 1.75-inches in diameter by 11.40 inches long and contain a pressed grain formulated to burn 90 seconds during static test. The flare compositions used in these evaluations are: (1) main flare composition: 33% Teflon®, 62% magnesium (22 $\mu$ m particle size), and 5% powdered anthracene, (2) booster composition: 28.5% Teflon®, 52.25% magnesium (22 $\mu$ m particle size), 14.25% ignition booster mix, and 5% powdered anthracene and (3) ignition booster mix: 46.3% zirconium (2.3 $\mu$ m particle size), 29.7% molybdenum trioxide, 19.0% chromic oxide, and 5% nitrocellulose.

In 1961, Mr. Sarnow of the Air Research and Development Command at WPAFB awarded a contract to the Midwest Research Institute of Kansas City, Missouri for a new type of flare that would produce a large cloud of finely divided radiating carbon particles formed by the decomposition of an acetylenic fuel. The prototype decoy used isopropenylacetylene (IPA) to generate the radiating cloud. The goal was to achieve a high signature in the 3 $\mu$ m to 5 $\mu$ m bandpass region. The radiating carbon

produced a greybody signature with insufficient energy to serve as a decoy. The concept for the decoy design is an aerodynamic shape with fins on the rear that looks like a pod. The size is 5.5 inches in diameter by 50 inches long. This shape is compatible with the AN/ALE-14 ejector system. The IPA is pumped into the interior combustion chamber where it is ignited with a hypergolic material to produce hot carbon and some thrust. When dropped from the B-52 bomber, the hot carbon cloud being released from the assembly becomes a decoy for the aircraft. Heaters were added because cold temperatures at high altitudes are a problem for efficient combustion. They considered external injection of chlorine trifluoride to increase the radiative output. If the latter failed, a bipropellant would be tried. Three prototypes were made and sent to NAD Crane for safety tests. There were problems with the acid pumps and corrosion. Eventually, the concept was abandoned because the spectral intensity was too low to serve as a decoy.

About 1966, Mr. John C. Trowbridge and Mr. William Lai of the United Technology Center, Sunnyvale, California (UTC) received a contract from the Research and Technology Division of Eglin Air Force Base to develop controllable infrared flares. They wanted to generate infrared signatures with a hybrid combustor. This is a burner-like device that supplies a gaseous oxidizer (oxygen) to a solid fuel surface. In this case the fuel grains are 2.5 inches in diameter by 12 inches long with a 1-inch hole through the entire grain. The fuels are either a castable rubber base or a methymethacrylate polymer base. Varying the oxidizer and the basic fuel controls the output. Shrouding the flare improves altitude performance. Some purported advantages are start and stop capability, controllable infrared radiancy, handling and storage safety, and manufacturing simplicity.

In a related experiment, United Technology provided hybrid flares for test. These consisted of a cylindrical hollow flare grain wherein flowing gaseous oxygen is ignited by burning propane. The units are 24 inches long by 3.5 inches in diameter. The grain consists of polybutadiene, polybutadiene-acrylonitrile, and polymethylmethacrylate with various amounts of aluminum as a fuel. The combustion could be started and stopped. The units were tested in a no-wind and wind environment, the latter being 50 to 60 knots. They wanted to use these units on drones carrying Radio Frequency (RF) systems and to determine compatibility between RF and infrared systems.

In 1967, Dr. Edwards of Air Development Test Center at Eglin Air Force Base, requested Picatinny Arsenal to improve the ALA-17 flare. The Air Force wanted a quick fix to the poor rise time of the ALA-17 flare. They also required that a single ALA-17 flare would have decoy capability to protect B-52 bombers in Southeast Asia against seekers operating in the  $2\mu\text{m}$  to  $3\mu\text{m}$  and  $3\mu\text{m}$  to  $5\mu\text{m}$  bandpass. This resulted in the development of the ALA-34 flare, which has a grain twice the length of the ALA-17 flare.

While the Mk 46 Mod 0 flare was in production during 1969 at NAD Crane, China Lake and Crane teams were asked to replace the RAPEC ignition mix with a safer

mix and to take a closer look at the pull wire igniter from a safety point of view. Mr. Allen of China Lake proposed a sodium azide-Teflon® igniter mix as a substitute for the RAPEC mix. Engineers at Crane did not support this mixture because of its azide content. Another proposed mix, supposedly less friction and electrostatic sensitive than RAPEC, was 57% sodium azide, 12% Teflon® #7, 31% boron, and 4% polymethylvinyltetrazole binder. China Lake also proposed another igniter mix, which was a vapor-deposited vacuum coated aluminum-tungsten trioxide material. The effort continued during 1970. Potassium azide and lithium azide were also considered by China Lake as a replacement for the sodium azide. Cab-O-Sil, which is fumed silica, was added to improve its effectiveness.

During 1969, NOTS explored three different igniters for the Mk 46 Mod 0 flare these being a plug release igniter, a shoulder-stop igniter and a pneumatic igniter. Dr. Raison and Mr. James Ross of the Illinois Institute of Technology Research Institute completed their contract for the miniaturization of the pneumatic igniter in mid-1969. In 1970, China Lake reported that the shoulder-stop ignition device is best of the four ignition ideas based on a value engineering study. The shoulder-stop ignition device was incorporated into future decoy designs.

In 1969, China Lake pointed out the need for compositions that were more effective in the 3µm to 5µm bandpass region. They suggested that the compositions be tailored to aircraft such as helicopters and that the compositions be more effective against multi-bandpass seekers. Emphasis is placed on the need for more power in the 3µm to 5µm bandpass region.

The China Lake team began thinking about a miniature flare for helicopters in the mid 1969 time frame. They proposed to develop a 1-inch diameter by 4-inch long flare. Later, the Mini-Flare was reported to be 2.75 inches long.

Three different grain designs were proposed for study by China Lake in 1969. These are an internal 8-point star, an internal-external burning grain, and grain that is burning only on the exterior surface. The grain designs needed to fit into the Mk 46 Mods flare configuration, that being 1.43 inches in diameter by 5.81 inches long. This configuration is compatible with AN/ALE 29 and AN/ALE 39 flare chaff dispensers.

Mr. James W. Richardson of NAD Crane explored qualification of ground and balled (atomized) magnesium for infrared decoy flare production as described in a 1971 report. The objective of this effort is to prove that either ground magnesium or atomized magnesium is suitable for use to manufacture infrared decoy flares. After all the qualification tests were conducted, which provided positive results, the production drawings were amended to allow the contractor the option to choose either type of magnesium to produce the flares required by the contract. The qualification effort involved the Mk 42 Mod 0 flare, the Mk 43 Mod 0 flare, the Mk 46 Mods, and the Mk 48 Mod 0 flare.

With respect to manufacturing improvement of the cartridge case, China Lake evaluated a redesigned 2-piece flare case joined by a magnaform process, which uses a high magnetic field to make the joint. Development of improved grain configurations and infrared composition was also continuing at China Lake during 1971. Performances of composition PL 7078 and composition PL 6720G with added graphite were compared. Both compositions extrude well. China Lake made grains with a 12-point internal star configuration and with a 12-longitudinal holes configuration. They reported that composition PL 6920G burns more quickly than composition PL 7078. The radiant intensity in both the 2 $\mu$ m to 3 $\mu$ m and 3 $\mu$ m to 5 $\mu$ m bandpass region was greater for composition PL 6920G. The 12-point internal star grain configuration burned more rapidly than the 12-hole grain configuration for both composition PL 6920G and composition PL 7078. This performance trend is similar for changes in altitude, wind velocity and ignition orientation. Composition PL 6920G with the 12-hole design had a very short rise to peak radiant intensity. The same design and composition was evaluated for radiant intensity at 40,000 feet altitude with 600 feet per second simulated airflow in the 2 $\mu$ m to 3 $\mu$ m and 3 $\mu$ m to 5 $\mu$ m bandpass region. The 2 $\mu$ m to 3 $\mu$ m bandpass region was greater in infrared radiant intensity than that in the 3 $\mu$ m to 5 $\mu$ m bandpass region.

Mr. Raymond Szypulski in NAVAIR as reported in a 1971 report assigned China Lake the task to develop second generation infrared flares with more infrared output in the 3 $\mu$ m to 5 $\mu$ m bandpass region and less in the 2 $\mu$ m to 3 $\mu$ m bandpass region. Dr. Handler, Mr. Harp, Mr. Sbrocca and R. Stassart of China Lake undertook this task. Their thrust was to develop formulations that have the desired spectral output by exploring metal/metalloid reactions with fluorine and oxygen containing oxidizers and to find binders that are not likely to form graphitic forms of carbon in the plume in order to maintain spectral purity rather than greybody radiance. To improve flare efficiency, their goal was to gain understanding of the physical processes, which occur on or at the burning surface. To further the idea to eliminate graphitic carbon originating from the Vitel® or Viton® A polymers, they considered many binary systems, which avoid these binders. They tried mixtures of aluminum, boron, calcium, calcium disilicide and magnesium with complex fluoride oxidizers. The best were potassium hexafluorophosphate and either calcium disilicide or aluminum as the fuel. They noted the spectral inversion was also observed in a complex system containing magnesium, potassium hexafluorophosphate, ammonium perchlorate and either Vitel® or Viton® A as the binder. They also considered high-oxygen-containing binders that do not have a sustained carbon-to-carbon backbone to obtain binder systems that would not produce graphite upon pyrolysis. Prototypes of these materials are the commercially available acetals and formal polymers Celcon® and Delrin®.

Continuing in 1972 toward their thrust to achieve a better color ratio (aka spectral inversion) between the 3 $\mu$ m to 5 $\mu$ m and 2 $\mu$ m to 3 $\mu$ m bandpass region. Mr. H. W. Kruse and Mr. Sbrocca of NWC, China Lake evaluated both pressed and cast compositions by introducing additives to the basic magnesium-Teflon® formula. They reported the mixture of Vitel®, potassium hexafluorophosphate, and

ammonium perchlorate as being encouraging in the 3 $\mu$ m to 5 $\mu$ m bandpass region. The magnesium, ammonium perchlorate, potassium hexafluorophosphate and Vitel® PE 222 formula gave a good color balance but was too low in radiative intensity. The best formula for an improved color ratio using Sylgard® to make a cast grain was 46% magnesium, 28.9% ammonium perchlorate, 1.4% Viton® A and 23.5% Sylgard® 182, called formula 256. Since the time to peak intensity was excessive for the Sylgard® formula, they introduced an 8-point star grain and a center bore hole configuration to get a larger burning surface. Later work by Dr. Melvin P. Nadler and Mr. Sbrocca of NWC, China Lake reported the Sylgard® formula as being not worth continuing. It performed well at ground level but not at a simulated altitude of 25,000 feet. Sodium azide was considered to increase the burning rate and increase the radiant intensity without loss or band ratio reversal. They proposed a new binder system R-45M hydroxyl terminated polybutadiene and possibly a castable fluorocarbon. Other fuel and oxidizer combinations were proposed in an attempt to produce chemical species, which emit in the 3 $\mu$ m to 5 $\mu$ m bandpass region. A pressed boron-Viton® A-ammonium perchlorate composition was tried in an attempt to produce boron oxyfluoride, the monomer of trifluoroboroxine. The monomer is stable at high temperatures and has band emissions in the 3 $\mu$ m to 5 $\mu$ m bandpass region. Small pellets of (1) boron-Teflon®-ammonium perchlorate, (2) boron-potassium hexafluorophosphate-ammonium perchlorate, and (3) boron-ammonium perchlorate-Viton® A were tested to see if they would burn. All burned at ground level, but only boron-ammonium perchlorate-Viton® A system looked promising. Pressed grains were also made with potassium hexafluorophosphate, fluoropolysiloxane (FS 1265 fluid), and Celcon® an acetyl copolymer based on trioxane supplied by the Celanese Corporation of America.

Mr. Foote and Mr. Michael Mamula of China Lake also were working to increase the color ratio. Using the EX 49 Mod 0 flare as their base design, they evaluated hardware changes for better ignition, studied different grain configurations such as the 12-point star and 12-hole variants to achieve greater surface areas, and additions of different amounts of graphite. After improving the ignition, test firings in mid-1972 indicated that the 12-hole configuration gave a combustion profile closer to the desired regressive burning. Ignition problems continued with the EX 49 Mod 0 flare, which by early 1973 was designated the Mk 49 Mod 0 decoy flare. Changes were made to the crimp at the mouth of the flare case. Further ground testing at NAD Crane and air testing at the Point Mugu test center showed that the ignition problems had not been resolved. This put further development of the Mk 49 Mod 0 flare into jeopardy. Some of the ignition problems were attributed to the CT-144 ignition mix.

Mr. Kruse and Mr. Breitengross of NWC as reported in 1971 were assigned the task to improve the efficiency of the infrared flare combustion reaction. They observed that some energetic ingredients do not react efficiently because of physical separation between the fuel and oxidizer. To overcome this deficiency, they attempted to coat the fuel with an oxidizer. They were aware of the work at the Illinois Institute of Technology Research Institute, which does the inverse; that is to

coat aluminum onto oxidizers such as tungsten trioxide, vanadium pentoxide, and potassium perchlorate by decomposition of an aluminum alkyl. The NWC China Lake team tried coating of boron with barium chromate and boron with potassium nitrate using non-aqueous solvents.

Work continued at NWC China Lake during 1972 to improve flare performance efficiency of magnesium-Teflon®-Viton® A (MTV) compositions and those containing Vitel® as well.

An urgent message dated 5 May 1972 directed the development of a flare to protect helicopters and low slow fixed wing. The problem was that although the AN/ALE-29A chaff dispenser existed which could dispense the Mk 46 Mod 0 decoy flare or the Mk 47 Mod 0 decoy flare, the dispenser had not been fitted to helicopters. In the interim, the helicopter operators wanted protection now. In response to this deficiency, the NWC team used N-35 propellant also called composition PL 9001 for the infrared radiating medium to make the Mk 50 Mod 0 decoy flare. The Mk 50 Mod 0 flare is launched from the AN-M8 pyrotechnic pistol. Units were immediately tested against the Redeye seeker, a surrogate for the SA-7 ground-to-air infrared missile threat. Two thousand decoys were shipped to the fleet in June 1972, a remarkable feat. Decoys were also shipped to Air Force units in Southeast Asia. NOS Indian Head followed with production of 50,000 units. Since there were no dispensers on helicopters, protection was achieved by a hopefully tethered crewman stationed in the doorway of the helicopter manually firing a Mk 50 Mod 0 flare from the hand-held AN-M8 pistol at the smoke trail of incoming missiles. This was the interim solution until dispensers could be installed, which then could dispense the existing Mk 46 Mod 0 decoy flare or Mk 47 Mod 0 decoy flare. Production of the Mk 50 Mod 0 decoy flare continued during 1973.

In 1973, NWC China Lake proposed to design and fabricate a large flare about 2.75 inches in diameter by 8 inches long. They planned flight tests to demonstrate feasibility that this large decoy flare was capable of providing protection to an aircraft such as a fighter while operating with the afterburners engaged.

Dr. Clyde F. Parrish, Mr. James E. Short, Jr., and Mr. William T. Biggs of NAD Crane reported an alternate method for production of Mk 48 Mod 0 flares in 1973. Their method is based on the radiation polymerization of a binder/oxidizer system. Chlorotrifluoroethylene, the monomer used, is completely polymerized by radiation doses less than 5 megarads. Because of the density involved, no special adjustment for concentration of either the oxidizer or fuel is needed. The voids in the magnesium are simply filled with the gaseous monomer.

As a part of a high Mach flare study by Mr. S. W. Lim in 1973 and configuration studies by Mr. J. O. Vindum in 1973 and Mr. John T. Lamberty in 1971, a 1973 report describes development of a shielded flare in the ALA-17 flare configuration for the AN/ALA-20 ejector set. They compare the radiant intensity in the 3µm to 5µm bandpass region of a freestanding grain to a perforated can flare. The

perforated can is four times better in maximum infrared output and has a better rise to peak intensity. In an early design, a conical nose shield is placed on the nose of the device to shield the combustion products from degradation due to the windstream. They also investigated the perforated can concept theoretically. Analysis showed the mass flow rate and ignition rise were improved significantly over the freestanding grain. They surveyed possible new fuel and oxidizer materials including conventional, pyrophoric and hypergolic for use in infrared flares. They considered several concepts for a flare such as a (1) rocket propelled with fins and a perforated can on the nose end, (2) rocket propelled, Telejet, Teleskirt, with a perforated can on the nose end, (3) perforated can flare with a shock wave cone on the nose, (4) time delay flare, (5) tethered flare, and (6) a perforated can flare in a cylindrical shape. These concepts were tested in a chamber at 2.0 Mach and at 50,000, 40,000, and 20,000 feet simulated altitude. The perforated can was made of steel, with 48 ports each 0.25 inches in diameter. A 2.682-inch diameter by 4 inches long pellet consisting of 58.3% magnesium, 38.8 Fluon®, and 2.9% Laminac® is assembled into the can. During the effort, the investigators developed a method for predicting the plume size of a flare burning in a supersonic windstream. They also created a mathematical model for the ignition of a flare in windstream and developed a flare trajectory computer program.

Dr. Donald. J. Eckstrom, Mr. P. H. P. Chang, and Mr. Robert T. Rewick of Stanford Research Institute (SRI) Menlo Park California reported studies of advanced flares in 1982. They wanted to achieve a better color ratio between the 3 $\mu$ m to 5 $\mu$ m bandpass region and the 2 $\mu$ m to 3 $\mu$ m bandpass region by introducing additives to the basic magnesium-Teflon®-Viton® A composition. The preferred ratio is for the long wavelength to be significantly larger than the short wavelength. After exploring candidate molecular emitters in the 3 $\mu$ m to 5 $\mu$ m bandpass region, they stated the best composition was 32% magnesium, 14% Teflon®, 14% Viton® A, 37% potassium perchlorate and 3% carbon. The mixture gave a 2.5 fold increase in the color ratio and only a 25% reduction of energy in the 3 $\mu$ m to 5 $\mu$ m bandpass region. They stated the best emitter was carbon dioxide. They added isotopic carbon 13 to counter atmospheric attenuation.

### **Pyrophoric Flares, Liquid or Solid Materials**

Prior to 1968, Dr. N. W. Rosenberg and Mr. W. K. Vickery of the Air Force Cambridge Research Laboratory (AFCRL) Laurence G. Hanscom Field, Bedford Massachusetts and Dr. D. B. Ebeoglu of Eglin Air Force Base reported measurement of infrared emissions from liquid pyrophoric fluids consisting of a mixture of 80% trimethylethylene (TME) and 20% triethylaluminum (TEA). They observed that the material was not affected by altitude when dispensed at 10, 000 feet and that the power was reduced by a factor of 10 at speeds of 275 knots in comparison to static performance.

In 1968, Mr. Leonard Spialter of the Chemistry Research Laboratory, Aerospace Research Laboratories at the Office of Aerospace Research of WPAFB considered

the potential of pyrophoric materials for use as infrared decoys. He excluded hypergolic materials in the study but included metallic powders, organic powders, inorganic and organometallics. He made a simple model as follow-on to the MS thesis of Major Norman Quigley in September 1967 - March 1968 at the Air Force Institute of Technology (AFIT). In his model, Mr. Spialter took into account the size of the fireball, loss of forward velocity, centroid seeking, paired clouds, etc. In the model, the target is traveling at Mach 0.9, the missile is traveling at Mach 2.0 and the altitude of the encounter is 50,000 feet. Dispensing 20 grams per second and at a standoff distance of 0.5 miles, radiance values are 4 kW/sr. He predicted the vulnerability envelope for the pyrophoric fireball to be about 44% of a conventional flare, that the fireball effectiveness is not greatly improved by increasing the diameter, and that dual ejections had an advantage and gave increased protection when ejected at proper time intervals. He conducted ground emission experiments at Eglin Air Force Base in March 1968.

Under contract to Mr. Vickery of the Aeronomy Laboratory at AFCRL, Dr. Katz, Mr. Ase and Dr. Raison formed a team at the Illinois Institute of Technology Research Institute to study liquid pyrophorics for countermeasures. The team made small-scale laboratory studies on the rheological and combustion properties of aluminum alkyls with a number of additives. Larger scale work was extended to flight tests in which 2-pound and 4-pound charges of pyrophoric materials were dispensed from an F-100D aircraft at 10,000 feet altitude while infrared measurements were made with an F-4C aircraft trailing 10,000 feet behind. All the pyrophoric materials exhibited very rapid rise times of less than 0.250 seconds and very high intensities in the long wavelength 3.9 $\mu$ m to 4.9 $\mu$ m region. Intensity was much lower in the region of 1.7 $\mu$ m to 2.7 $\mu$ m. They compared their results to the RR-80 flare. They stated that the ratio in the two wavelength regions could be useful for countermeasure against two color seekers. Mixtures tested included TEA and TMA in a range of mixtures with octane, pentane and polyisobutylene.

At the request of the NOL White Oak, about 1971, Mr. Ronald L. Blecher and Mr. Reagan Layne Dubose Jr. of Hycor, Inc., North Woburn Industrial Park in Woburn Massachusetts explored explosive dissemination of a gelled pyrophoric fuel intended for a ship decoy defense system. Triethylaluminum was the principal pyrophoric fuel in the study. In 1974, based on experiments during an Internal Research and Development Program (IRAD), Dr. A. Hirschman of NOL White Oak stated that the gelled pyrophoric of triethylaluminum did not work. This prompted the Hycor team to change to a ceramic felt wick saturated with a mixture of 75% TMA and 25% TEA. The wick is about 1 square inch and holds about 2 grams of material. They recorded the radiant intensity of a single wick in the 8 $\mu$ m to 14 $\mu$ m bandpass region and in the 3 $\mu$ m to 5 $\mu$ m bandpass region. They planned to load 1000 wicks into a Rapid Blooming Offboard Chaff (RBOC) cartridge. Their goal was to achieve a fall rate of less than 5 feet/second and an apparent temperature in the 8 $\mu$ m to 14 $\mu$ m bandpass region of at least 50 °C when viewed against a zero degree Celsius background. After initial laboratory investigations, they planned to test the RBOC round against captive threat surface-to-surface missile seekers.

Dr. D. B. Ebeoglu and Mr. C. W. Martin of the Armament Laboratory at Eglin Air Force Base and Dr. N. W. Rosenberg and Mr. W. K. Vickery of AFCRL at Hanscom Field undertook infrared signature measurements under static and dynamic environments. The experiments were conducted in chambers at Eglin Air Force Base and NWC China Lake and the results were reported during a 1974 meeting. Using kerosene as a reference they tested six pyrophoric materials in the laboratory and measured the radiant intensity in the 2 $\mu$ m to 5 $\mu$ m bandpass region at 60,000 feet simulated altitude with wind speeds of 300 feet/second. The six materials were: TEA, tri-n-propylaluminum (TNPA), diisobutylaluminum hydride (DIBAH), diethylaluminum chloride (DEAC), a mixture of 80% TMA with 20% TEA by weight, and a mixture of 60% diethylaluminum hydride (DEAH) with 40% TEA by weight. The flight test at 10,000 feet altitude gave ambiguous data. They concluded that pyrophoric materials offer a high radiation figure of merit in the 4 $\mu$ m to 5 $\mu$ m bandpass region and also in the 2.5 $\mu$ m to 3.3 $\mu$ m bandpass region with no airflow. They reported that the infrared signature from pyrophorics is not affected from sea level to 60,000 feet altitude. They could not model the effects of wind adequately. Their overall conclusion is that pyrophorics were promising as infrared decoys.

In 1973, Mr. Vickery of AFCRL at Hanscom Field requested NWC China Lake to measure the radiometric and spectrometric characteristics of TEA, TNPA, DIBAH, DEAC, DEAH, and a mixture of 66.5% TEA and 33.5% DEAH. Investigators at the AVCO Systems Division Wilmington Massachusetts also participated. Infrared radiant intensity data were collected at 40,000, 30,000, 20,000, and 10,000 feet altitude in both still and moving airstreams.

Mr. L. J. Larson of Hycor Inc conducted an Advanced Cost Effective (ACE) flare program for the Avionics Laboratory at WPAFB. The 1981 report covers work started in 1978. The objective of the ACE project was to develop a pyrophoric flare design, which was compatible with the current ALA-17 pyrotechnic flare canister and the AN/ALE-20 dispenser system for the B-52 bomber aircraft. A key technology to be addressed was to develop a means of metering the liquid fuel to achieve adequate burning times and radiant intensities. Several flare designs were tested. One had a bladder in the inner case. Another used a piston to expel the pyrophoric fuels. Typically the fuel was a mixture of TMA, TEA, and DEAH. Diethylmagnesium (DEM) or DEAC is added to reduce the freezing point of the mixture. The spectrum of jet fuel was compared to the pyrophoric fuel mix. A tethered design was tested to reduce tumbling. Two sizes tested were 2.5 inches in diameter by 5 inches long and 2.5 inches in diameter by 10 inches long. The long design was prompted by the poor reliability of the ALA-17 flare and the AN/ALE-20 dispenser, which made it necessary to dispense two or more flares to protect the B-52 aircraft. The long flare would replace the need for dispensing two flares.

About 1982, Dr. William E. Howell, Dr. John A. Lafemina, and Mr. Gary Roan of NRL were developing decoys compatible with the AN/Mk 36 Launcher for surface ship protection. Pyrophoric foils, emissive chaff and catalyzed carbon cloth were

being evaluated. They obtained temperature-time profiles for each material type, and radiance, area, and spectral measurements. A team lead by Mr. J. Ganjei at the Naval Research Laboratory (NRL) studied catalyzed combustion of carbon fibers from carbon fiber-resin composites. Mr. Ganjei, Dr. H. D. Ladouceur and Mr. A. Saunders also of NRL studied how a liquid pyrophoric can ignite carbon cloth. Impregnating the cloth with 10% lead acetate lowers the spontaneous ignition temperature of the cloth. They also studied aluminum foil backed materials ignited by a triisobutylaluminum alkyl and noted that TEA and TMA can also be used. They proposed using carbon particulates for aircraft decoy flares.

Mr. James R. McDougal, Mr. Robert R. Gross, and Mr. Gary P. Anthony of Boeing in 1982 conducted an effectiveness analysis of pyrophoric and pyrotechnic flares in defense of strategic aircraft against two-color missiles. They constructed a digital model for that purpose, conducted the analysis and concluded that pyrophoric flares offer substantial improvements over pyrotechnic flares, that upward ejection is not optimum, and that a two second burning time is the absolute minimum.

### **Castable Compositions for Decoys and Flares**

In the early 1960s, researchers were exploring manufacturing processes for making decoy flare grains. The shock-gel process (aka coacervation process) during that time period was used to prepare infrared composition, which then is extruded to make MTV grains. Mr. Kruse and Dr. Handler of NOTS explored a modified vacuum-casting process to make infrared flare grains. If successful, the vacuum-casting process was expected to improve the efficiency of grain manufacture over the coacervation process. Example binders that they investigated were fluoroacrylates, fluoromethacrylates, Viton® LM, and Viton® LM cross-linked with carboxy-terminated polybutadiene (CTPB). The composition made by the vacuum-casting process contained 18-25% by weight of the binder ingredient. They reported the infrared output of grains made by the vacuum casting process in the 2µm to 3µm bandpass region to be comparable to grains made by extruding MTV.

A U. S. Patent 2,984,558 for a Plastic Pyrotechnic Compound by Mr. Edward Rolle and Mr. John Q. Tabor, Jr. dated 16 May 1961 addresses a tracking flare with composition that can be cast or molded at room temperatures without the application of either heat or pressure, and which will harden without developing cracks or fissures. The patent discloses a formula that is equal amounts by weight of a resinous compound and a fuel. The resins are Laminac® Resin #4128 and Laminac® Resin #4134, both unsaturated polyester resins. The fuel is 1-part magnesium powder (70% through 325 mesh) and 2-parts potassium perchlorate or ammonium perchlorate as the oxidizer.

Development of compositions with polymeric melt system technology is disclosed in three patents. U. S. Patent 3,094,444 for Solid Composite Propellants Containing Lithium Perchlorate and Polyamide Polymers by Mr. Ross M. Hendrick and Mr. Edward H. Mottus dated 18 June 1963 discloses a mixture that is heated to 225 °C.

A homogeneous fluid viscous mass results at that temperature. U. S. Patent 3,067,074 for Slow Burning Propellant Composition by Mr. William A. Gey of NOTS dated 4 December 1962 describes a mixture of molten Teflon® with a solid oxidant. U. S. Patent 3,013,871 for a Gas-Generating Composition by Mr. Paul O. Marti, Jr. dated 19 December 1961 uses a softened plasticized styrene-acrylonitrile copolymer as a binder fuel.

About 1962, Mr. Cronk of Eglin Air Force Base sponsored a task to conduct research and determine feasibility of castable infrared flares. Dr. Waite, Mr. Paul M. Kirkegaard and Mr. Richard A. Whiting of Flare-Northern performed the work. The team noted that after seven years of work related to the magnesium-Teflon® flare composition, a problem still remains with compositions containing Kel-F® wax. Those compositions exhibit unsatisfactory ignition and unsatisfactory combustion at altitudes above 100,000 feet and show marked attenuation in radiative output and a decrease in burning rate with altitude and airflow. In addition, the combustion tends to snuff-out at velocities above Mach 3. The researchers claimed some improvement of properties is available through use of wet-blended and pressed grains of magnesium-Teflon® with radiation enhancement additives. However, they asserted that significant improvement in the state-of-the-art for infrared chemical sources must evolve from the use of a new source material. They claimed to have developed such a material in the form of a bulk polymerizable fluorocarbon that replaces the Teflon®. They made cast flares based on acrylic and methacrylic esters of fluoroalcohols. One example is copolymerization of fluoroheptylmethacrylate with fluorocarbons. They also made liquid/slurry flares based on fluorophthalate esters of the above alcohols. Their theoretical analysis of fuels other than magnesium showed no improvement over magnesium when substituting them for magnesium. The investigators also explored anthracene and phenanthrene as additives. They reported that chaff-loaded or staples-loaded cast flares increased the linear burning rate from 0.03 to greater than 0.2 inches per second and also were better at altitude. To further the technology, the team attempted to make ultraviolet radiating flare compositions based on aluminum and aluminum perchlorate and made cavity flares to enable tailored combustion properties.

In 1966, Dr. Hal Waite formed Ordnance Research Incorporated (ORI) Fort Walton Beach Florida. There he continued his fluorocarbon polymer and cast flare composition development primarily under contract with the Air Force at Eglin Air Force Base.

Mr. Sarnow of the Avionics Laboratory at WPAFB funded the Flare-Northern Division of the Atlantic Research Corporation to develop a solid cast source. The objective was to incorporate a solid cast infrared flare in a dispenser system compatible with the AN/ALE-20 dispenser installed in an Air Force bomber aircraft. In 1965, Mr. Reed of Flare-Northern reported that end burning cast units did not burn fast enough even with additives. His base mixture consisted of polyfluoroheptylmethacrylate (PFHM) and magnesium. Next he made star-

perforated grains to accelerate the burning rate. He also introduced tetrachloroanthraquinone, violanthrone, pyranthrone, tetrakis-(anthraquinoneyl amino)-anthraquinone and isoviolanthrone as additives. He added 0.032 diameter copper wire (similar to staples or chaff in this application), which he placed axially into the center of the grain. With this he achieved a four-fold burning rate increase. He also tried three silver wires placed axially 120 degrees apart. This technique also increased the burning rate. He concluded that the flare with the internal burning star, with isoviolanthrone as an intensity additive, and aluminum chaff as a burning rate accelerator was the best combination.

In 1965, NOTS investigators continued to explore the propellant casting process to make infrared flares. The binders were fluoroacrylates and fluoromethacrylates. Viton® LM, being less expensive than acrylates, was used as a plasticizer. Magnesium was the fuel and Teflon® was the oxidizer. A modified vacuum casting process was used to load the flares. As part of this work, Dr. Handler of NOTS China Lake explored the solubility of magnesium perchlorate in various polymers. The maximum solubility of magnesium perchlorate into a mixture of 2 parts butylacrylate with 1 part acryloacrylate is 50%. He also explored the solubility of magnesium perchlorate in vinyl monomers and other binders like fluoroacrylates-methacrylate in a Viton® LM polyamine system. Dr. Handler also evaluated binders containing oxidizers for cast flares.

### **Missile and Rocket Igniter Developments**

In early 1944, Dr. Hart at Picatinny Arsenal studied coating agents for magnesium and magnesium-aluminum alloys. During that period, it was customary to use linseed oil to protect magnesium from moisture and to act as a binder in tracer and other pyrotechnic compositions. In this instance, metal powder is coated by immersion in a 5 percent aqueous solution of sodium dichromate and sodium hydrogen sulfate at room temperature. The coated magnesium was tested in igniter compositions in 37mm tracer ammunition. During the study, Dr. Hart observed that (1) finer magnesium is more reactive with moisture than is coarser magnesium, (2) 50/50 magnesium/aluminum alloy is less reactive with water than either magnesium or aluminum alone, (3) the presence of strontium nitrate improved the resistance of magnesium to the reaction with water and (4) sodium oxalate accelerates the reaction of magnesium with water. He stated that no earlier work to coat powdered metals was found.

As the work progressed, in 1944 Dr. Hart developed an improved igniter "K" composition containing dichromated 50/50 or 65/35 magnesium/aluminum alloy instead of magnesium. Extended storage tests of the improved igniter composition demonstrated it to be more stable at elevated temperatures and high relative humidity and also less sensitive to friction than the standard igniter "K" composition. With good test results during firing tests at Aberdeen Proving Ground Maryland in 1945, they recommended putting the improved igniter composition into 37mm and

40mm tracer ammunition and to study using the dichromated fuels in larger caliber ammunition.

In 1948, NOTS began design of the folding-fin aircraft rocket (FFAR). The initial H-9 propellant was replaced with N-4 propellant in the fall of 1950. The use of the N-4 propellant introduced a low temperature ignition problem into the Mk 125 Mod 0 igniter then in use. Mr. N. C. Eckert of NOTS conducted an investigation of low temperature ignition. He modified the charge in the igniter to consist of 8 grams of black powder and 2 grams of vinyl-coated magnesium powder. This modified igniter is designated the NOTS Model D634 Igniter.

The NOTS Model D634 igniter gave satisfactory ignition in the NOTS Model 103G 2.75 inch rocket motor above minus 40°F with failures below that. The NOTS Model 103G motor is the prototype of the 2.75 inch Mk 1 Mod 1 rocket motor. By May 1951, a redesigned igniter was developed. It was designated the NOTS Model D639 igniter later to be designated the Mk 125 Mod 2 igniter. Mr. Eckert of NOTS is credited with the development of the Mk 125 Mod 2 igniter. The NOTS Model D634 igniter and the Mk 125 Mod 2 igniter have the same charge, namely 8 grams of black powder and 2 grams of vinyl-coated magnesium powder. The Mk 125 Mod 2 igniter was incorporated into the 2.75-inch NOTS Model 103H rocket motor, which is the prototype of the 2.75-inch Mk 1 Mod 2 rocket motor. Later, it was observed that the Mk 125 Mod 2 igniter had a problem with the reaction of moisture with the magnesium powder. That subject is discussed in the section on Hydrogen Formation from the Magnesium-Moisture Reaction.

Federal Ordnance Incorporated (FOI), Mechanicsville Maryland produced the 2.75-inch FFAR rocket motor Mk 1 Mod 3 containing a Mk 125 Mod 2 igniter manufactured by Federal Ordnance Incorporated. The US Flare Corporation (USFC), Pacoima California also manufactured a Mk 125 Mod 2 igniter. At minus 65 °C, there were induced incipient hangfires in the Mk 1 Mod 3 motors with the igniters made by Federal Ordnance Incorporated but not with igniters made by the US Flare Corporation. This investigation assigned by the Navy BuOrd to NOTS lasted from October 1954 through February 1955. The lack of proper quantity of magnesium in the charge and non-homogeneity of the mixture are the assigned causes for the Federal Ordnance Incorporated igniter failures.

### **Atmospheric Pressure and Altitude Effects**

It had been observed that when flare compositions are required to function at elevated altitudes and reduced pressure, performance drops off. Often the burning rate decreases and the radiant intensity is reduced. These undesirable effects are a major concern and many efforts were initiated to correct or at least minimize those flare performance deficiencies. After all, fighters and bombers will use the infrared decoy flares for self-protection at very high speeds and very high altitudes.

About 1959, Mr. Knapp of Picatinny Arsenal was under contract to the Air Force to develop an infrared flare that radiated in the 1.8 $\mu$ m to 2.8 $\mu$ m bandpass region. A composition identified as SI-119 was reported to be unaffected by increasing altitude up to 60,000 feet and above which it tapers off slightly. The constituents are molybdenum trioxide, chromic oxide, and zirconium. The peak energy output in watts and the efficiency in joules/gram or joules/cubic centimeter increased with altitude although the burning rate was constant with altitude. Mr. Knapp reports that in the first 12 seconds of combustion, the SI-119 composition is superior to Teflon® compositions. Compositions consisting of manganese dioxide-zirconium and molybdenum trioxide-barium nitrate-zirconium are reported to have very good ignition and burning characteristics at both high and low altitudes.

As part of an MS thesis from US Naval Postgraduate School, Monterey California, in 1962, a student studied the pressure dependence of the solid-state reaction between magnesium and Teflon®. He observed that at about 350 mm Hg ambient atmospheric pressure, the percentage of completion of the reaction dropped off exponentially to 12 mm Hg, the lowest pressure considered. He reported decomposition of Teflon® at about 425 °C and melting of magnesium at 650 °C. Steady state burning was observed at about 650 °C, the melting point of magnesium.

During the early and mid 1960s, NOTS engineers continued to study flare performance at high altitudes. They needed a method to obtain infrared output performance data of flares under actual use conditions. They installed a modified fuel tank under the fuselage of an A-4E aircraft and attached the flares to radial arms extending from the front of the tank and attached a radiation detector to a rear fin 14 feet from the flares. Associated electronics were mounted inside the tank. Feasibility flights at 30,000 feet altitude and 0.8 Mach indicated that the radiometer response was insufficient. They studied the discrepancy in the HARP facility. They also brought additional instrumentation to the task to determine the cause of the performance fall-off with altitude.

Functioning at very high altitude is a requirement of the magnesium-Teflon® composition. To further understand its behavior, in 1961, Mr. Besser of NOTS conducted studies for use of this composition for rocket grain igniters at 70,000 and 100,000 feet simulated altitude.

About 1961, Mr. F. Harshbarger and Mr. R. Herman of the General Dynamics Corp (GD), San Diego, California tested six flare formulations in their altitude chamber. US Flare Division of the Atlantic Research Corporation prepared the six test units. The test units are an end burning grain, 2.5 cm in diameter by 20.3 cm long. The grain weighs 150 grams and is made up of the NOTS Standard formula consisting of 54% magnesium gran -16, 30% Teflon® #1 600 $\mu$ m particle size, and 16% Kel-F® #10 wax. To that grain formulation two test units had lithium perchlorate and anthracene added, one test unit had tetranitrocarbazole and Epon 864 an epoxy resin added, and two test units had nitrocellulose and silicon dioxide added. These

test units were tested in the General Dynamics altitude chamber, which is 6-feet in diameter by 40 feet long and is capable of 92,000 foot simulated altitude. The thrust of the work is to determine the effect of altitude on the spectral output of the flares. A Perkin Elmer Model 108 rapid-scan spectrometer was used to obtain the spectra in the 1 $\mu$ m to 2.5 $\mu$ m and 2.5 $\mu$ m to 5 $\mu$ m bandpass region. The temperature was measured with a Leeds and Northrup optical pyrometer. At altitudes above 40,000 feet, the General Dynamics team reported the spectral radiance decreased as the altitude increased and the brightness temperature decreased with increasing altitude. The burning time generally increased with increasing altitude.

## **Inhibiting Technology for Flares**

It is necessary to prevent the combustion reaction from flashing down the side of a flare grain ahead of the desired flame front in order to obtain smooth and efficient burning. Modifying or protecting the surface of the flare to prevent such undesirable ignition is known as inhibiting. During the early 1960s, Dr. Handler explored the use of 16 different inhibitors. He applied these to 1-inch diameter grains made with composition PL 6328, namely 54% magnesium gran -16, 30% Teflon® #1, and 16% Viton® A. Three different epoxy-coating agents seemed successful at ambient and cold temperatures. NOTS China Lake researchers also treated the surface of the extruded grain with hydrochloric acid before coating the grain with the inhibitor to improve adhesion.

As the work continued, the China Lake team learned that four commercially available resins prevented flash down on extruded grains made with composition PL 6328. Grains (0.913 inches in diameter) also were co-extruded with an inhibitor layer approximately 0.1 inch thick of 16% Viton® A, 35% titanium dioxide, and 35% carbon black. These methods did not materially affect the efficiency of the flares.

Work continued at NOTS China Lake into the early and mid 1960s to inhibit burning on the exterior of extruded and pressed infrared grains consisting of the magnesium-Teflon®-Viton® A formula. Grains with these formulations are difficult to inhibit. The non-sticking properties of Teflon® in the composition make adherence of the inhibitor difficult. Inhibiting the grain is a way to control the burning rate better. The NOTS investigators tried epoxy and proprietary coatings as well as wrapping with ethyl cellulose and/or glass tape. The burning times were longer with the tapes than for the resins with some exhibiting burn-through.

## **Burning Rate Modification**

Dr. McEwan, Mr. Alvin S. Gordon, and Mr. Joseph Cohen, all of NOTS China Lake, developed a method in 1953 for increasing the burning rate of propellants by introducing metal wires such as copper, silver, aluminum, molybdenum, tantalum, and lead into the composition. The wire had to be a good conductor and have a high melting point. It was intended that these short lengths of highly conductive wires would conduct the heat generated at the combustion site into the composition

more rapidly to further promote the propagation of the flame front and thereby accelerate the burning rate. They made a submission for patent that was awarded as a Notice of Allowability on 5 August 1959. This concept was applied later to infrared decoy pressed and extruded compositions without success. With respect to decoy compositions, the addition of a few percent of conductive wire, then called staples or chaff, has an insignificant effect on increasing the burning rate. This is because decoy compositions already have a high content of conductive metal, for example 54% magnesium.

In 1975, Mr. K. L. Moore and Mr. Breslow of NWC conducted burning rate modification studies. Their approach was to thermally decompose diborane in a fluidized bed. They planned to make boron coated aluminum and magnesium by chemical vapor deposition of the decomposed diborane.

### **Gasless Delay Mixtures**

In 1943, the U. S. Army standardized a nickel-potassium perchlorate delay developed by Mr. Owen G. Bennett and Mr. Jack Dubin for use in M204, M205, and M206 hand grenade fuzes. Their U. S. Patent 2,457,860 for Delay Fuse Compositions issued on 4 January 1949. This gasless delay mix consisted of powdered zirconium, powdered nickel, barium chromate, and potassium perchlorate. The barium chromate was used to regulate the burning rate. The Bennett delay was later replaced by a dichromated zirconium-nickel alloy delay developed by Dr. Hart of Picatinny Arsenal.

A new non-gaseous fuze powder for the M16-A1 delay elements for bombs containing barium chromate, manganese, and sulphur was developed about 1944 by Dr. Hart. It is better than the standard lead chromate-silicon delay.

An improved barium chromate delay powder for the 8 to 11 second delay was developed a year later by Dr. Hart, which contains 70.9 parts barium chromate, 27.1 parts manganese, 2 parts sulphur, and 2 to 3 parts ethyl cellulose. It is more stable, affected less by moisture, and more readily pelleted than the standard powder. An igniter, which can readily be pelleted, was developed containing 85 parts red lead, 15 parts silicon, and 2 to 3 parts ethyl cellulose.

During 1949, Dr. Hart started to develop a gasless, non-hygroscopic fuze powder. He conducted a detailed study of the burning characteristics of binary mixture containing barium chromate with zirconium and titanium. The use of zirconium powder involves considerable hazard. Hence, he went to a less hazardous zirconium-nickel alloy. The metals were protected with a dichromate.

Dr. Hart pointed out during his 1956 lecture that black powder customarily used to make delays, is an explosive and presents some hazards. To overcome the disadvantages of black powder as a delay powder, Dr. George C. Hale at Picatinny Arsenal, began work in 1929 on the development of non-gaseous delay powders,

making use of inorganic exothermic reactions similar to those used in thermite mixtures. The first non-gaseous delay powder was developed in 1931 for the M16-A1 primer detonator used in a bomb fuze. It contained red lead, silicon, and glycerine, the latter added as a binder. Even in small quantities, organic binding agents such as glycerine and linseed oil produce a significant amount of gas upon combustion.

During WW II and concurrent with the work going on at Picatinny Arsenal, a non-gaseous delay powder was developed by the Catalyst Research Corporation of Baltimore Maryland working under contract with the Navy and the Army Ordnance Corps. This composition contained catalytic nickel, zirconium, potassium perchlorate, and barium chromate. This mixture is based upon the exploitation of four simultaneous exothermic reactions having different burning rates. Although this delay powder was used successfully during WW II for hand grenades, there were difficulties similar to those encountered with the barium chromate, manganese, and sulfur delay powder. The burning rate was found to decrease with age. The nickel powder had to be produced under carefully controlled conditions by a special patented mercury amalgam process. The particle size of the zirconium required careful control for reproducible results. However, the powder appeared to be more stable in the presence of moisture than the barium chromate-manganese-sulfur delay powder.

### **Hydrogen Formation from the Magnesium-Moisture Reaction**

The formation of hydrogen resulting from the reaction of moisture with magnesium powders plagued energetic compositions containing magnesium powder for a very long time. During 1944, Dr Hart of Picatinny Arsenal reported the dichromating of magnesium powders in igniter compositions for 37 mm tracer ammunition in order to reduce the undesirable formation of hydrogen. He coated the magnesium by immersion in a 5 percent aqueous solution of sodium dichromate and sodium hydrogen sulfate at room temperature. He stated that he found no earlier work to coat powdered metals. Up to that time, magnesium and aluminum fuels had been coated with linseed oil to provide protection and to serve as a binder of the composition. Dr. Hart observed further that the finer the magnesium granulation the more reactive with moisture, that the presence of strontium nitrate improved the resistance of magnesium to the reaction with water, and that sodium oxalate accelerates the reaction of magnesium with water.

Mr. Louis Lo Fiego of the Bermite Division, Whittaker Corporation Saugus California reported that in 1945 as one of his last duties as an officer in the U. S. Navy during World War II, he had the task to destroy unserviceable pyrotechnic items returned from the South Pacific. Black powder used in many pyrotechnic trains failed to ignite or sustain burning after being subjected to high temperature and humidities. In many cases the potassium nitrate in the black powder separated from the sulphur and carbon, forming beautiful crystals. This negated the usefulness of black powder as an ejection or ignition charge in pyrotechnics. Black powder delay trains were

found to burn erratically or not at all. Magnesium powder was found deteriorated because moisture reacting with the magnesium formed hydrogen gas, magnesium oxide and magnesium hydroxide. At the end of World War II, the general consensus was that the performance and reliability of pyrotechnics left much to be desired.

As reported in a 1951 report, Mr. Donat B. Brice of the Rockets and Explosives Department at NOTS conducted an evaluation of chromated magnesium powder as an igniter material and concluded that the potassium dichromate washed magnesium powder as an igniter component gave the same performance as observed previously with vinyl-coated magnesium powder. In this instance, the igniter material is a mixture of 50% coated magnesium and 50% potassium nitrate, by weight. This mixture was under consideration for use in igniters suitable for ignition of ballistite. Ballistite is a smokeless propellant made from two explosives those being nitroglycerine and nitrocellulose.

Starting work in August 1953, Mr. Ralph M. Moon, Jr. of the Rocket Department at NOTS, China Lake studied the evolution of gas from coated magnesium-black powder igniter mixtures. The Mk 125 Mod 2 igniter for the NOTS Model 103H 2.75-inch FFAR rocket motor developed sufficient pressure to burst the blowout disc. Mr. Wiebke of China Lake reported that a mass spectrographic analysis revealed that the gas released when the blowout disc yielded was 95% hydrogen. The hydrogen was formed by a reaction between the vinyl-coated magnesium and moisture in the black powder in the igniter charge.

### **Effectiveness Tests of Flares Against Missiles**

In conjunction with WPAFB during 1955-1956, the Engineering Research Institute, Willow Run Laboratories at the University of Michigan conducted captive field tests of the Falcon GAR-1B air-to-air missile. They simulated the missile with a modified analog computer such as the one owned by the Eastman Kodak Company at that time. In the simulations, they considered dropped decoys, towed decoys, smoke, dust and blinking countermeasures.

Under a contract with WPAFB in 1957, Mr. Breymaier of the Willow Run Laboratories at the University of Michigan managed the dispensing of flares from the B-52 bomber and the B-47 bomber at Eglin Air Force Base to test their effectiveness against the Aerojet Engineering Corporation Aerowolf air-to-air missile, the Hughes air-to-air Falcon missile, and the Navy Bureau of Ships Atmospheric Sounding Projectile (ASP). Towed decoys and "blinking" techniques were also examined. Flare trajectories were determined by film reduction, a very tedious process. In 1958, the researchers declared, "The flare is the most important infrared countermeasure at the present time. Other countermeasures appear to have certain significant disadvantages. The most important characteristics of a flare are its infrared radiation intensity compared with the target, its trajectory relative to the target, and its burning time."

In the early 1960s, Mr. H. L. Toothman and Mr. C. M. Loughmiller of the Naval Research Laboratory conducted decoy effectiveness tests of the Mk 46 (Mod unspecified but believed to be the Mod 0) flare against the ATOLL AA-2 air-to-air missile. The F-4B and the F-8 were the target aircraft. The test emphasized ejection direction and varying speeds with the objective of determining the optimum location of the flare launchers on the aircraft. Among their objectives was to evaluate flare parameters, which might allow flare redesign with proper radiancy and burning time. They recorded radiative intensity versus speed at launch and the degradation of power with increasing airspeed. They constructed a model using inputs from China Lake for the missile parameters and inputs from the Naval Research Laboratory of the atmospheric transmission in the infrared spectrum.

In 1965, Mr. E. S. Clemens and Dr. Edwards of the Air Proving Ground Center, Eglin Air Force Base reported radiometric measurement of the ALA-17 flare and the QRC-127 flare intended as penetration aids for the B-52 bomber. Both flares are compatible with the AN/ALE-20 dispenser and function at Mach 0.75 and at 35,000 feet altitude with 90% reliability. For radiometric measurements, they used a T-8 seeker, which is an Aerojet-General T-8 radiometer mounted in the nose of a B-47 bomber. The radiometer operates in two bands. The head includes a tracker (seeker) that uses FM track techniques as well as a radiometric capability. Both flares showed poor effectiveness in the 3.5 $\mu$ m to 5.5 $\mu$ m bandpass region but 100% effectiveness in the 2 $\mu$ m to 2.7 $\mu$ m bandpass region. The data from the T-8 seeker were extrapolated to the GAR-4A (AIM-9G) missile and with some success to the GAR-2A (AIM-4C) missile and the GAR-8 (AIM-9B) missile. The tests showed the importance of a fast rise time to peak intensity. The trajectory was satisfactory. Considering the difficulties of extrapolating data, they recommended that operational type seekers be used in future tests.

In 1970, the Operational Test and Evaluation Force (OPTEVFOR), at Norfolk Virginia evaluated the AN/ALE-29A dispenser and the Mk 47 Mod 0 flare. When deployed from the AN/ALE-29A dispenser of an F-4 aircraft or an F-8 aircraft operating at less than military rated power, the Mk 47 Mod 0 flare was found to effectively decoy the threat missile guidance system. Neither the F-4 aircraft nor the F-8 aircraft is adequately protected by the Mk 47 Mod 0 flare with afterburner operating.

In 1970, Mr. Harp and Dr. Handler of NWC China Lake tested the Mk 46 Mod 0 decoy flare at 25,000 and 50,000 feet simulated altitude and high airflow. They observed extremely reduced infrared output. They also flight tested preproduction Mk 46 Mod 0 flares and the EX 49 Mod 0 flares at 30,000 feet altitude against the AIM-9C Sidewinder missile. The flight tests were conducted during 1971 by VX-4 at Point Mugu. In addition, a flight test was conducted to determine the infrared effectiveness of Mk 46 Mod 0 flares when dispensed from an HH-1K aircraft. Mr. Harp also determined the effectiveness of the EX 49 Mod 0 flare as an infrared decoy. The China Lake team continued to define factors relating simulated and

actual flight test results. In addition, they initiated development of a facility for obtaining spectral measurements of flares under simulated flight conditions.

### **Comparative Flare Testing and Signature Measurements**

In mid-1956, under contract to WPAFB, Eastman Kodak Company investigators recognized that infrared measurements were of primary interest although ultraviolet and microwave band measurements also needed to be considered. They measured flare radiative output at 10,000 and 40,000 feet altitude. They also measured the infrared signature of the B-47 bomber, the B-52 bomber and the B-66 bomber with an infrared scanner mounted in the nose of an RB-47 aircraft. In about the same time frame, efforts were being made to calculate the radiative output of rocket motors.

Mr. R. G. McCarty and Mr. H. Wair of NOTS, China Lake reported on the effectiveness of the NOTS Model 704 decoy flare against the Sidewinder missile in December 1958. Based on results from 1958 tests of infrared augmentation devices, the Air Proving Ground Center, Eglin Air Force Base conducted an evaluation to determine altitude effects on the TAU-15 flare performance. This occurred about 1960. Airborne flare measurements were accomplished at 30,000 feet from the instrumented B-47 aircraft flying in-trail with a B-57 bomber or T-33 aircraft towing a Del Mar Laboratory Radop TDU-4/B radar-reflective aerial tow target carrying the test flares. The tow target, equipped with four flare holders and a remote flare ignition system, was towed with 10,000 feet of cable. The measured radiometric data varied considerably. This deficiency was the basis for a further study to devise instrumentation and techniques to provide better measurements.

An early 1959 Eglin Air Force Base report describes ground and airborne infrared energy emission measurements of five aircraft and eight augmentation devices in the 1.8 $\mu$ m to 2.7 $\mu$ m bandpass region. Aerial measurements were made on T-33, B-57, RB-66, B-47, and B-52 aircraft to assess what type of augmentation device would be needed to simulate the aircraft signature. The infrared augmentation devices measured on the ground for radiant intensity versus burning time were the TAU-15/B (NOTS Model 711) flare, the T-245-3 flare, the W-211 flare, the USFC W111B flare, the Mk 3 Mod 0 (BB-9) flare, the W-211/A-5 flare, the UMC-94 flare and the UMC-95 flare. The TAU-15/B (NOTS Model 711) flare, the T-245-3 flare, the W-211 flare, the NOTS Model 702A flare and the Mk 3 Mod 0 (BB-9) flares were measured while airborne at 26,000 feet altitude and 175 KIAS. Depending upon the flare type at these flight conditions, the flares burned longer by 35% to 100% and the infrared intensity decreased by 10% to 30%. More detailed flare descriptions are in the FLARES DESCRIPTIONS section.

In 1961, Mr. Nichols and Mr. Sumnicht of the Aviation Ordnance Department at NOTS acquired five different types of flares from the Naval Astronautics and Missile Test Center, Point Mugu, California, all of which had similar dimensions though produced by different manufacturers. NOTS investigators made ground-to-ground

infrared radiation measurements of flares mounted on a 20-foot tower at an optical path length of 500 feet. The humidity was near 35%. The Denver Research Institute of the University of Denver provided infrared flares from contract AF 08-(635)-1402, Aerojet-General provided infrared flares given AF Part No. 60D-22348, Special Devices, Inc of Hughes Aircraft Company provided infrared flares given AF Part No. 60D-22390, and the US Flare Division of the Atlantic Research Corporation provided two flare types identified as the Model No. W204 and Model No. W205. All produced greybody type radiation with no specific emissions.

The Air Proving Ground Center, Eglin Air Force Base Aerojet-General, Armour Research Foundation of the Illinois Institute of Technology, Kilgore, Lambert Engineering, Picatinny Arsenal, and Universal Match Corporation developed the infrared countermeasure test devices under Air Force contracts.

In early 1963, some 1960 vintage TAU-15 flares failed to burn at 0.7 Mach and 35,000 feet altitude even though the squib had fired successfully. The failures varied lot-to-lot, with altitude, and with the internal temperature of the individual flares. After the engineering investigation at the Air Proving Ground Center, Eglin Air Force Base, it was recommended that the TAU-15/B flare be replaced by an improved substitute.

Three different target flares, namely the W205 Lot 2 flare, the AGX0827 flare, and the TAU-56/B flare, were prepared for the Aeronautical Systems Division Detachment 4 at Eglin Air Force Base to be used in ground-to-ground and air-to-air tests. NOTS provided their locally developed color-wheel radiometer for radiometric measurements. Tests were conducted in the Air Test and Evaluation Squadron Four facilities at Point Mugu. The flares were mounted on a TA-7 aerial tow target manufactured by the Hayes Corporation and used in various forms by the Navy and the Air Force. They recorded burning time and effective radiant intensity in 0.5 $\mu$ m intervals in the 2.0 $\mu$ m to 6.0 $\mu$ m wavelength band while towing the target at altitudes between 5,000 and 50,000 feet at towing speeds of 0.5 Mach to 0.95 Mach.

There was a plan about 1964 to conduct high altitude and wind tunnel tests on a NOTS Model 729B augmentation flare and on a contractor developed Mk 37 Mod 0 flare used on the AQM-37A target drone. The parameters to be included in three related tests are (1) sea level, ambient conditions, and Mach 0.9, (2) 70,000 foot simulated altitude (33.6 Torr) at ambient temperature and Mach 2, and (3) 70,000-foot simulated altitude, minus 65 °F and Mach 2.

NOTS investigators extruded flare pellets, which were assembled into NOTS Model 715B target flares by the US Flare Division of the Atlantic Research Corporation. Twenty-four of these pellets were put in a circular drum of the AN/ALE-18 pneumatic chaff dispenser for test. Mr. Carter of NOTS in late 1963 reported ground-to-ground and air-to-air testing of these units.

Capt Lazarus Lebanoff USAF of the Air Proving Ground Center at Eglin Air Force Base described the measurement and evaluation of infrared flares in ground tests and flight tests at 20,000 to 30,000 foot altitude in a May 1964 report. The flares tested were the W205 flare, the W112B flare, the W211F flare, the TAU-15/B flare, the TAU-56/B flare and the AGC flare. All of these operational flares contain the magnesium-Teflon® composition. The scope of the tests included the determination of burning time and measurement of radiant intensity in both long and short wavelengths at sea level and at flight altitude. An additional purpose of this test was to derive a correlation between sea level and flight altitude flare performance.

Mr. R. E. Davis of ARO, Inc. reported on radiant intensity measurements acquired in March 1966 of two types of infrared flares. ARO, Inc. is a subsidiary of Sverdrup & Parcel and Associates, Inc. and is a contract operator of the Arnold Engineering Development Center, Arnold Air Force Station, Tennessee. The work was done at the request of the Air Force Armament Test Laboratory (AFATL) Research and Technology Division (RTD) Eglin Air Force Base Florida. Radiant intensity measurement from two types of pyrotechnic infrared flares over three wavelength bands were obtained at Mach 2.0 and Mach 1.75 and at simulated altitudes of 70,000 feet and 60,000 feet. The tests were conducted in the 16-foot supersonic tunnel. The flares were mounted on an AQM-37(A) drone missile installed in the tunnel test section. Testing consisted of radiometric measurements of flare irradiance over the wavelength bands of interest and subsequent determination of flare burning time. Results of the test indicate, especially for results at Mach 2.0 and in general for those at Mach 1.75, that radiant intensities and burning times of NOTS Model 729 flares were notably greater than corresponding results from Mk 37 Mod 0 flares. Radiant intensity measurements over all wavelength bands showed approximately twice the emitted flare radiant intensity at Mach 1.75 at an altitude of 60,000 feet as compared to radiant intensity at Mach 2.0 at an altitude 70,000 feet.

About 1966, the Aeronautical Systems Division at WPAFB sponsored a study at the Cornell Aeronautical Laboratory to review the performance of 28 decoy flares for the Penetration Evaluation (PENVAL) program, which encompassed the analysis and evaluation of tactical penetration aids.

In 1966, Mr. Craig Fenn, Mr. David Lyons and Mr. Edward Mattson of the Eastman Kodak Company conducted radiation measurements of rectilinear configured flares for the Aeronautical Systems Division at WPAFB. The Eastman Kodak team used a modified Perkin Elmer Rapid Scan Spectrometer Model 108 and a two-channel radiometer. No descriptions of the flares are given except to say that the flares were from the Illinois Institute of Technology Research Institute (3-types), Universal Match Corporation, Unidynamics, Central Technology Inc, and the Flare-Northern Division of the Atlantic Research Corporation.

In 1966, at the request of the Air Force, an Interservice Support Program was set up to perform acceptance testing and evaluation of the AN/ALA-17 flare at NOTS.

The tests were to be conducted in the NOTS 10 foot by 10 foot by 100-foot dark tunnel and the NOTS 16-foot diameter by 32-foot long altitude chamber.

A joint Air Force/Navy exercise was held at China Lake about 1966 to obtain airborne radiometric data, trajectories and functional capability of rectangular configured infrared flares, which were compatible with the USAF 669A Phase-I dispenser. The 2-inch by 2-inch by 5-inch flares were from four contractors. The Armour Research Foundation of the Illinois Institute of Technology provided the RR-115 flare, Unidynamics provided the UM-111 flare, Flare-Northern Division provided cast flares and Space Ordnance Systems provided the RR-119 flare.

About 1968, Mr. Claunch and Mr. Regelson of China Lake obtained infrared signature measurements of the A-4F, F-100, F-4C and OV-10A aircraft. In addition, Mr. J. Morris Weinberg of Block Engineering reported jet aircraft and missile exhaust spectra obtained by use of an interferometric spectrometer.

Under a 1968 contract, the Targets and Missiles Division of Eglin Air Force Base contracted with the Martin Marietta Corporation, Orlando Florida to determine the output of hybrid and selected pyrotechnic decoy flares. Mr. J. L. Durand and Mr. D. E. Sukhia of Martin Marietta took infrared measurements of a UTC hybrid flare, the W251 106E flare, the TAU-56 105E flare and the TAU-15 107E flare. They tested the units in a no-wind and wind environment, the latter being 50 to 60 knots. Their goal was to determine if these units could be used on drones carrying RF systems and to determine the compatibility between onboard RF and infrared systems.

In mid 1968, Mr. Breymaier, Mr. Hodge W. Doss and Mr. Yuji Morita of the Willow Run Laboratories at the University of Michigan conducted a flare study for ECOM at Fort Monmouth. They computed flare trajectories for those flares that would fit the AN/ALE-29 dispenser. Their objective was protection of UH-1, CH-47, and OV-1 type aircraft. They varied ejection velocities, speed, and ejection angles to determine zones of effectiveness.

Testing continued at NOTS of the Mk 46 Mod 0 flare and the Mk 47 Mod 0 flare at ambient and 20,000 feet simulated altitude, at 250 knots, and at 552 knots when ejected from aircraft. Both flares show greater radiant intensity in the 3 $\mu$ m to 5 $\mu$ m bandpass region than in the 2 $\mu$ m to 3 $\mu$ m bandpass region in static test at 2,500 MSL and at simulated altitude of 20,000 feet. They compared upward and downward ejection of the Mk 46 Mod 0 flare and Mk 47 Mod 0 flare for effectiveness against the AIM-9D Sidewinder missile.

Mr. Harp and Dr. Handler of NWC China Lake in 1970 conducted a thorough comparison of the Mk 46 Mod 0 flare with the Mk 47 Mod 0 flare. They concluded that neither the Mk 46 Mod 0 flare nor the Mk 47 Mod 0 flare could protect the RF4-J aircraft in military rated thrust from the Sidewinder 1C because the flares lacked sufficient infrared radiated power. However, protection of the RF-8 aircraft with these flares is satisfactory. In 1971 they reported tests of the Mk 46 Mod 0 flare as

a function of altitude and airflow in their high altitude simulation chamber in the 2 $\mu$ m to 3 $\mu$ m and 3 $\mu$ m to 5 $\mu$ m bandpass region. NAD Crane provided the flares for this test from a pre-production lot.

The spectral signature of the Mk 46 Mod 0 flare and the Mk 47 Mod 0 flare were measured in 1970. Mr. William Hyman and Mr. Lawaha Parrish of Army Missile Command Redstone made infrared measurements in 1973 of the Mk 46 Mod 0 flare and the XM-196 mini-flare. They measured the Mk 46 Mod 0 flare dropped from an A-4E aircraft at 400 knots and from a UH-1H helicopter at 100 knots. They also measured the XM-196 flare from the UH-1H aircraft at 100 knots and obtained infrared signature measurements of the aircraft during the same trials.

About 1970, Mr. Robert H. Roberts of ARO Inc. under contract to the Arnold Engineering Development Center, Arnold Air Force Station determined the separation characteristics of a TFAF flare from the F-4C aircraft at Mach 0.50 to 0.95. Infrared spectra were taken of both engines of the F-4C aircraft while in afterburner. Wind tunnel experiments were also performed at the Arnold Engineering Development Center, Arnold Air Force Station, Tennessee.

In the late 1970s, Mr. Persky of Block Engineering statically measured infrared spectral and spatial radiation from the ultraviolet and infrared regions of four flare formulae. Two formulae consisted of ammonium perchlorate, aluminum and a binder. The other two formulae consisted of Teflon®, ammonium perchlorate and a binder.

During May 1971, investigators of the Missile Electronic Warfare Technical Area, White Sands Missile Range New Mexico performed a series of experiments to determine the spectral radiant intensity of flares used with the Ballistic Aerial Target System (BATS). They made measurements at different aspect angles with flares fired in a static position.

During 1971, NWC China Lake investigators continued the evaluation of the Mk 46 Mod 0 decoy flare. They measured the radiant intensity at 380-400 knots and 25,000 feet altitude. Upon another occasion, they evaluated a preproduction lot of Mk 46 Mod 0 flares made at NAD Crane and EX 49 Mod 0 flares from MSL to 50,000 feet altitude at various airspeeds. At altitudes of 25,000 to 40,000 feet, the EX 49 Mod 0 flares burned about 2.6 seconds whereas the Mk 46 Mod 0 flares burned about 9 seconds. Both had serious ignition problems at altitude. The infrared power output of the EX 49 Mod 0 flare was considered to be too low. The EX 49 Mod 0 flare was tested from an F-4 aircraft at 30,000 feet to evaluate the ignition reliability.

In 1971 the Naval Air Systems Command asked China Lake to obtain infrared radiant intensity measurements of "scintillating flares" provided by Aerojet-General. Flares were measured in the 2 $\mu$ m to 3 $\mu$ m and 3 $\mu$ m to 5 $\mu$ m bandpass region using interference filters under ambient conditions and at reduced pressures simulating

altitudes from 7,500 to 40,000 feet altitude. The output fluctuated sinusoidally at 16-17 hertz. No data on the flare configuration or composition are available.

In 1973, EX 49 Mod 0 decoy flares were shipped to the White Sands Missile Range for extensive flare flight tests at altitudes of 1,500-6,500 feet above ground level and airspeeds from 230 knots to 600 knots. Later, in cooperation with the Agile missile and AIM-9L Sidewinder programs, flight tests of the EX 49 Mod 0 flares were to be conducted at 40,000 feet altitude to determine if the improved igniter performance previously observed at lower altitudes would be maintained at high altitude.

In 1973, the Aeronautical Systems Division at WPAFB requested China Lake to obtain infrared measurements of RR-119 flares at various altitudes to determine conformance with specification requirements. The RR-119 flare is compatible with the AN/ALE-28 dispenser in the F-111 aircraft. Flare-Northern/Celesco Industries provided contract flares for comparison with standard Air Force flares. Thiokol Chemical Corporation Wasatch Utah provided flare grains prepared by a cast method. Data were recorded from tests at ground level, 15,000 to 17,000 feet altitude and at 30,000 feet altitude in the  $2\mu\text{m}$  to  $3\mu\text{m}$  and  $3\mu\text{m}$  to  $5\mu\text{m}$  bandpass region. Later, Flare-Northern provided additional flares for evaluation at 70,000 feet altitude. The cast flares had a much lower infrared radiant intensity in the  $3\mu\text{m}$  to  $5\mu\text{m}$  bandpass region.

The Air Force at Hill Air Force Base in 1973 tasked Flare-Northern/Celesco Industries to evaluate eight flare racks from October 1968 and January 1969 production lots of AN/ALA-17 flare cartridges for possible extension of their service life. The tests were to include simulated altitude at 35,000 feet and 55,000 feet, burning time, and radiant intensity in spectral bands nominally covering the  $2\mu\text{m}$  to  $3\mu\text{m}$  and  $3\mu\text{m}$  to  $5\mu\text{m}$  bandpass region.

About 1973, Naval Air Headquarters asked China Lake to attempt to qualify a second industry source for infrared augmenters. NWC compared the infrared augmenters 3090N made by DynaTech Inc (DTI) to the Ballistic Aerial Target System (BATS) flare made by Flare-Northern/Celesco Industries.

By 1982, emphasis was to obtain infrared and performance measurements of production flares. Mr. Kenneth D. Meyer of General Dynamics Pomona was tasked to measure variations of the M206 flare and a production MJU-7/B flare. Variants of the M206 flare were: (1) an extruded grain containing ground magnesium, (2) an extruded grain containing atomized magnesium, and (3) production units. The MJU-7/B flare production units contained a pressed grain, as did one of the M206 flares. Power, trajectory, and spectra were obtained of the decoys launched from an M-130 dispenser mounted in a UH-1H helicopter operating at 60 knots and 120 knots.

## **Missile Countermeasure Techniques Development to Defeat Flares**

Between August 1954 and November 1958, Aerojet-General conducted research on airborne infrared countermeasure techniques. The objective of that work is infrared detection and warning equipment for bombers. The design goal of the equipment is to detect air-launched, rocket-powered missiles at five miles or more.

The first field tests to determine the ability of a counter-countermeasure algorithm in the missile to discriminate against infrared flare decoys were initiated at NOTS in January 1961. Initial tests were conducted at ground level with captive flight tests following later that year. The ground tests results were in complete contradiction to the missile captive test results at altitude. This prompted Mr. J. F. Dibrell of the Bureau of Naval Weapons to contract with the Illinois Institute of Technology Research Institute for a study to determine the effect of air velocity on infrared flares. Dr. Raison and Mr. Richard T. Price of the Illinois Institute of Technology Research Institute conducted the work. The NOTS Model 704K target flare and the NOTS Model 704H target flare were used in the study. They concluded that air streams corresponding to those occurring in normal flight significantly reduce energy output from the flares on the order of a factor of ten in the spectral region between 1 $\mu$ m and 5 $\mu$ m. Previously, these reductions had been attributed to the reduced pressure at altitude. In 1963, NOTS investigators did improved discrimination techniques tests and more ground tests. Because of inconsistent and unexpected results, they decided to do more airstream tests as well.

Mr. E. J. Chatterton of Lincoln Laboratory Massachusetts Institute of Technology (MIT) reported a study of infrared modulation discrimination of flames and flares about 1962. He suggested that this feature might be used in a seeker to discriminate between different sources. He included flares consisting of magnesium-Teflon®-Kel-F® wax in the study.

### **Modeling and Simulation**

Investigators at WPAFB in 1957 reported an analog simulation capability to estimate vulnerability reduction to the B-52 bomber by dispensing decoy flares from an RR-77 flare assembly housing. As modeled, the decoys were 3.5 inches diameter by 3.5 inches long and weighed 0.44 pounds.

During 1961 through 1964, Mr. Breymaier of the Willow Run Laboratories at the University of Michigan headed up a team that conducted simulation and analysis of infrared countermeasures for Mr. Sarnow of the Air Force Avionics Laboratory at WPAFB. They reported that simulation showed flares at missile launch or at preemptive launch gave good protection but noted that a controlled trajectory flare might be better. They also noted that a single free-fall flare gives good protection in the forward and rear hemispheres for considerable variations of target altitude and velocity. Their laboratory measurements showed that the required flare-to-target intensity ratio is a function of the target shape, seeker reticle design, angular

separation rate, and the rise-time of the flare intensity. The simulations included effectiveness consideration of the flare as a point source.

One of the tasks at the University of Michigan involved simulating the effectiveness of infrared flares against the GAR-2 Mach 4 missile, the latter having some frontal capability. The infrared seeking GAR-2 missile also known as the AIM-4B first appeared in 1956. One of the scenarios simulated was an attack of a Mach 3 aircraft at 30 degrees off nose at a 50,000-foot range. The work continued with the simulation of decoy flares against the GAR-8 (Sidewinder) missile and the GAR-K missile, the latter being a hypothetical air-to-air Mach 3 missile. Their interest was concentrated on protection of the B-58 aircraft from the forward hemisphere. In the evaluation, they used three flares called Type A flare, Type B flare, and Type C flare. The Type A flare and the Type B flare are 2-inch by 3-inch by 5-inch parallelepiped flares designed for gravity drops. The Type C flare, as reported in 1962, is a rocket-boosted flare that is fired forward from the aircraft. It has fins to provide aerodynamic stability. Initially, there is a thrust of 250 pounds for 0.5 seconds after which the unit is in free fall. All of the three flare types burn for about 10 seconds.

To determine the drag coefficient of burning flares, about which little is known in the early 1960s, Mr. Breymaier of the Willow Run Laboratories at the University of Michigan, used trajectory data from a flare launched from a rocket-boosted monorail sled test with a peak velocity of about 2,000 feet per second. The track is located at the Experimental Track Section of Edwards Air Force Base California. From these data, they calculated drag coefficients of the burning flare. Early information indicated that a flare has a high drag coefficient. Kilgore, Incorporated made the flares used for the trajectory experiments. The units were cylindrical, 5.75 inches long by 1.875 inches in diameter and weighed about 0.6 pounds. No known nomenclature for identification was assigned to these units.

In March 1968, Mr. Norman P. Quigley presented his MS thesis awarded by the Air Force Institute of Technology at WPAFB on a simulation study of an infrared countermeasure. He proposed a decoy with various parameters such as delay time, burning time, plume size and dual releases. He presented a mathematical model and simulated the decoy. He concluded that his proposed decoy could increase defense capability.

In 1968, Mr. Regelson of NOTS summarized the advantages and limitations of an infrared decoy flare. The advantages are: (1) ability to countermeasure simple missiles, (2) provides "point" targets, (3) has a small unit volume, (4) can be stowed in large numbers, (5) can be mass produced, (6) has low unit cost, (7) can fit existing stores and (8) is easily mounted on aircraft. The limitations are: (1) requires early warning, (2) increases visual detection, (3) require exact placement, (4) is susceptible to counter-countermeasure, (5) does not match target radiative wavelength, (6) is often unreliable at altitude, (7) requires special handling, and (8) requires a special dispenser.

Mr. R. J. Mador of Pratt & Whitney Aircraft division, East Hartford Connecticut reported a computer program for predicting infrared signatures.

Mr. Z. Newmark and Mr. J. Ratkovic of Hughes Aircraft Corporation Culver City California and Major H. C. Schlicht of the Air Force Avionics Laboratory at WPAFB developed and verified a mathematical model of the ALA-17 Flare, the Mk 46 (Mod unspecified) flare and a shielded flare. The team asserted that the IRCM community needed such a model because (1) no generic model was available, (2) flight test data were extremely limited, (3) flare intensity varies greatly with altitude and ejection speed, and (4) correlation between flight and static tests was found to be poor. With their model, they claim it is now possible to accurately predict the flare intensity profile for any ejection altitude, any speed, and in any spectral range. They reported a prediction of flare intensity profiles for altitudes from sea level to 40,000 feet, ejection speeds from 0.5 to 2.2 Mach and in five different missile-sensing bands. They made comparisons between measured and simulated profiles for the ALA-17 flare for several different flight conditions. Mentioned in a 1974 report.



## APPENDIX

### Earliest Record of Event or Concept

- 1929:** Development of non-gaseous delay powders begins.
- 1931:** First non-gaseous delay powder was developed. It was used in the M16-A1 primer detonator.
- 1938:** Teflon® was discovered by Dr. Roy Plunkett of E. I. Dupont.
- 1943:** Naval Ordnance Test Station, Inyokern, California is commissioned.
- 1944:** First practical lead sulfide detector developed in the USA.
- 1944:** First record that magnesium powder is dichromated for protection from moisture.
- 1949-1960:** Towed aerial decoy concept is evaluated.
- 1950:** Earliest record of addition of a fluorochlorocarbon (Kel-F® oil #10) to a binary mixture of magnesium and Teflon®.
- 1952:** 14 May: First flight-test of EX 0 Sidewinder missile.
- 1953:** Developed a method for increasing the burning rate of propellants by introducing good thermal-conducting high-melting metal wires such as copper into the composition: later known as staples or chaff.
- 1954:** NOTS concerned with infrared target augmentation since 1954.
- 1954:** The NOTS T-131 flare is the first infrared source for drone use.
- 1954:** Started RITA flare development for bomber aircraft protection.
- 1954:** Concept for Balls of Fire is introduced. This concept may have spawned variants such as the perforated can concept, shielded flare concept, wire mesh and annular-shielded flare concept and the jacketed flare concept.
- 1955:** Made prototype of a Roman-Candle type pyrotechnic flare package.
- 1955:** First addition of Kel-F® wax to a binary mixture of magnesium and Teflon®.
- 1955:** First attempt to develop a pyrotechnic covert decoy flare.
- 1955:** Noted that a showering action achieved a greater radiating surface area and that a showering flare was desirable because of the greater surface area that was radiating.
- 1955:** Recognized that signature suppression is needed, which will enhance decoy effectiveness.
- 1955-56:** Explored alternative decoy concepts such as dropped decoys, towed decoys, smoke and dust as an obscurant and blinking countermeasures.
- 1956:** E. I. Dupont Company was the first to market Viton® A.
- 1956:** Introduced Sidewinder missile into the US Fleet.
- 1956:** Composition formulation 54% magnesium, 30% Teflon®, and 16% Kel-F® wax was discovered in the spring of 1956.
- 1956:** NOTS Model 702 is the first application of a flare as a target tracking flare and is the forerunner of all IR flares. The composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® wax.

- 1956:** Jacketed-variant RITA Flares were housed in a perforated steel jacket. The perforated case design suggests similarity to the Balls of Fire or perforated can design concept wherein the flame spews simultaneously from all the holes in the surface of the flare case.
- 1957:** Introduced concept of an inflated envelope decoy that could be used as a free or towed target. The resultant decoy would be a large-area extended-source with a low effective temperature.
- 1957:** Infrared decoy flare development technology spread to the UK from the USA.
- 1958:** NOTS Publication series of documents started.
- 1958:** Development of a forward-launched/ forward-fired decoy concept was started. The concept was first proposed in 1954 during the Balls of Fire project.
- 1958:** Started to develop concepts for infrared flares optimized to radiate effectively in the 3.0 $\mu$ m to 5.5 $\mu$ m bandpass region.
- 1959:** First report of the Shock-gel process for making decoy flare composition.
- 1959:** First replacement of Kel-F $\text{\textcircled{R}}$  wax with Viton $\text{\textcircled{R}}$  A in a magnesium-Teflon $\text{\textcircled{R}}$  formula. Prior to 1959, Kel-F $\text{\textcircled{R}}$  wax was the standard material added to a binary mixture of magnesium and Teflon $\text{\textcircled{R}}$ .
- 1959:** NOTS Model 704A may have been the first countermeasure flare to have been developed.
- 1959:** The W137 flare is one of the earliest magnesium-Teflon $\text{\textcircled{R}}$  formulated flares. It dates to before October 1959.
- 1960:** The T-131 flare, the Mk 21 Mod 0 flare and the NOTS Model 702 flare are the most widely used tracking flares at NOTS.
- 1960:** First record (5 July) of an infrared composition with the exact formula 54% magnesium, 30% Teflon $\text{\textcircled{R}}$ , and 16% Viton $\text{\textcircled{R}}$  A. First extrusion of this composition is 10 November 1960.
- 1960:** NOTS Model 711A is first flare used for evaluation of weapon systems.
- 1961:** The RR-82 flare cartridge has "pop-out" drag fins to partially control the trajectory. This design may have been the first so-called aerodynamic flare decoy.
- 1961:** The first field tests to determine the ability of a counter-countermeasure algorithm in the missile to discriminate against infrared flare decoys were initiated at NOTS.
- 1961:** Early attempts to make a large-area source flare, which would produce a large cloud of finely divided radiating carbon particles
- 1962:** Earliest attempts to make infrared flares by the cast process.
- 1962:** Flare tested which has a thrust of 250 pounds for 0.5 seconds after which the unit is in free fall: This may be the first trial of the kinematic flare concept.
- 1963:** Attempt to develop a flare that would not be affected by windstream by adding a wire mesh shield in one case and in the other an annular shield with apertures to protect the combustion reaction from the windstream.
- 1964:** The perforated-can flare concept (related to the shielded flare concept) was considered for incorporation into a forward launched decoy flare design.
- 1967:** First attempt to create a pyrotechnic decoy that radiated in regions that correspond to radiative regions where aircraft radiate: spectral flares.

- 1967:** Collected relative radiative intensity versus Mach number data, which probably was the first time such information was recorded.
- 1968:** Recognized the need for 120-150 decoy flares on an aircraft operating in a dangerous area.
- 1968:** First report that impact from 50-caliber projectiles can ignite magnesium-Teflon®-Viton® A compositions. This led to the "bullet impact" safety requirement.
- 1968:** The Mk 47 Mod 0, which entered production in 1968, is the first decoy flare designed for use in the AN/ALE-29 dispenser.
- 1968:** Earliest record of attempt to generate infrared emissions from liquid pyrophoric fluids consisting of a mixture of 80% trimethylethylene (TME) and 20% triethylaluminum (TEA).
- 1969:** Solid carbon is identified as the primary emitter in the typical decoy magnesium-Teflon®-Viton® A flare.
- 1970:** Confirmed by designed experiment the marked reduction of infrared radiant intensity when flares are exposed to windstream. First time this characteristic of decoy flares was confirmed although the degradation had been noted for many years during tests.
- 1971:** Stated that an area-radiating source is better than a point source.
- 1972:** Roman Candle concept is advanced to make a flare using onboard fuel, gelling the fuel, followed by dispensing and igniting the gelled mixture as an infrared decoy.
- 1973:** In the mid-1970s, the RR-119 flare (Later variant) was the highest performing flare in production.
- 1973:** Attempt to develop a shielded flare to overcome flare performance degradation under high Mach windstream.
- 1974:** NOTS Model 723 is largest MTV flare ever constructed: 12 inches in diameter by 16 inches long and weighs 70 pounds.
- 1974:** Capability prediction that the FW355 flare, when used in conjunction with a missile-warning receiver, would give the FAC a fully automated IRCM system.



## Origin of the Pyrotechnics R&D Department at NAD, Crane

The following are excerpts from a paper presented by Mr. Louis Lo Fiego Bermite Division, in July of 1982 at the International Pyrotechnics Seminar in Steamboat Springs Colorado. He reported that in 1946, the responsibility for the development of pyrotechnic items for the U. S. Navy was assigned to NOL White Oak, which by 1982 became a part of the Naval Surface Weapons Center. The responsibility for research in pyrotechnics and the development of pyrotechnic items for the U. S. Army was assigned to Picatinny Arsenal, Dover New Jersey, which by 1982 evolved into the Army Research and Development Command. The Chemical Warfare Group at Edgewood Arsenal was responsible for screening and colored smokes. The Air Force depended on the Navy and Army for its pyrotechnic needs. During that period Dr. Hart, Head of the Chemical Research at Picatinny Arsenal made immeasurable contributions in advancing the state-of-the-art in pyrotechnics by innovative program planning and implementing these programs through talented personnel.

Mr. Lo Fiego goes on to say that a respected Army General, on his return from World War II stated that there would be no need for pyrotechnics in future wars because electronic and mechanical devices would replace pyrotechnics. Exceptions were photoflash bombs and smoke producing devices. The net result was that financial budgets established for pyrotechnic programs for 1946 through 1950 were minimal. Personnel in Government involved in pyrotechnics felt that in order to establish respect for their work, efforts should be directed toward meeting three objectives: (1) establish real and new needs for pyrotechnics, (2) develop pyrotechnic devices that would be considered ordnance items rather than fireworks, and (3) convert pyrotechnics from a black art to a science. The Navy's Operational Development Force at Boca Chica Florida while developing tactical procedures for Anti-Submarine Warfare (ASW) operations established a need for new aircraft parachute flares and marine markers to satisfy ASW requirements. This helped to reestablish important Navy pyrotechnic programs, which, for example enabled the development of the Mk 24 Mods series aircraft parachute flares. In addition, funds were provided to investigate and develop new and more reliable pyrotechnic compositions.

In 1947, the Navy planned to close the facilities for manufacturing pyrotechnic items at NAD Crane. This is the pyrotechnic production facility at Crane that was built during World War II to continue the production jobs that were transferred from the Navy's Baldwin Long Island pyrotechnic production plant when it closed in the early 1940s. Pyrotechnic administrative personnel in Washington DC Headquarters, who include Mr. Lo Fiego, convinced the Navy to maintain the production facilities at NAD Crane. This was accomplished by using development funds to employ and keep the key people at NAD Crane who had many years of experience in manufacturing pyrotechnics. As an example, the design work for a new illuminating projectile was accomplished at NOL White Oak and the prototypes were fabricated at NAD Crane.

Not losing these individuals proved to be very fortunate for the USA during the Korean War. Casualties were high in South Korea because of night infiltration by the North Koreans. As a result, the U. S. Air Force requested the Navy to produce and deliver as many aircraft parachute flares as possible to this area. The pyrotechnic personnel at NAD Crane met the challenge resulting in a letter of commendation from the Air Force. In essence, the letter stated that the flares permitted interdicting the enemy's advances and were instrumental in not losing the war in Korea. The letter helped the cause of pyrotechnics and was used to justify additional funds in the Navy's budget.

The staff in the Navy Headquarters was instrumental in establishing a group of technical personnel at NAD Crane for the production engineering of newly developed pyrotechnic devices. Later this group became the research and development arm for Navy pyrotechnics and deserves credit for helping advance the state-of-the-art and for developing items that are in the category of reliable ordnance items. Eventually, about 1955-1956, that group became the nucleus of the Pyrotechnics Research and Development Department at NAD Crane starting with a complement of about 20 persons.

## **Origin of the Technology Base for U. S. Military Pyrotechnics at Picatinny Arsenal**

Before WW II and after WW II in 1946, the state-of-the-art of pyrotechnics was not in good shape. Pyrotechnics was still an art and not a science. About 1947 at Picatinny Arsenal, there was a surge in armaments research and development caused by the technical and tactical shortcomings experienced on the battlefield. At that time, funding for pyrotechnics almost did not exist. This started to change in 1947-1948 when materiel development requirements by the newly established U. S. Air force, formerly the U. S. Army Air Corps, became a dominant factor. The U. S. Air Force was largely dependent for its ordnance upon U. S. Army Ordnance and in turn on the Army's arsenals and laboratories. At Picatinny Arsenal, this created a requirement for pyrotechnic munitions such as aircraft illuminating flares, rescue and distress signals, and photoflash bombs and cartridges for night aerial photography.

At Picatinny Arsenal, the pyrotechnics research, development, and engineering missions were executed within the Technical Group, subsequently renamed the Technical Division. Later, the Technical Division was renamed the Samuel Feltman Ammunition Laboratories and subsequently the Feltman Research and Engineering Laboratories. The latter continued to exist until the summer of 1960. Reorganization of the Technical Group into the Technical Division just prior to 1950 resulted in the elimination of major Branches and established Assistant Division Chiefs in four functional areas.

In January - February 1950, the Technical Division was reorganized again. The result was that Mr. Abraham L. Dorfman became Chief of Development and Engineering, Dr. David Hart became the Chief of Chemical Research, and Mr. Henry Eppig became Chief of Physics, Instrumentation and Testing. In late 1950, Mr. Dorfman became Chief of the Technology Division and Mr. Henry Cohen replaced him as Chief of Development and Engineering.

A major obstacle was the lack of sufficient funds for pyrotechnics research and technology. To overcome this obstacle, Mr. Dorfman chose to internally tax the well-funded hardware development and engineering projects and to use the accumulated funds for pyrotechnics research and technology. Without these research and technology funds, the U. S. Army's materiel advances in military pyrotechnics would have been minimal. All through the 1950s and into the early 1960s the Pyrotechnics Laboratory at Picatinny Arsenal was the sole research center among the U. S. Armed Services.

Mr. Dorfman writes that the presence of technical managers who perceived the absolute need for a sound technology base; the decision to start on the long road towards eventual realization; the conviction that hardware requirements could not

be met without a substantial investment in technology; and the availability of heavily funded hardware development projects that could be judiciously used for this purpose made the 1950s the crucial formative years for military pyrotechnics in the United States.

## A Brief History of Military Pyrotechnic Research Facilities in the United Kingdom

The UK facility<sup>11</sup> for military pyrotechnic research and development first commenced at Woolwich Arsenal, and was then built up to meet the pyrotechnic requirements of the First World War. One of the Woolwich scientists who was central to the development of UK military pyrotechnics was Mr. Jack C. Cackett who was known as “The father of UK pyrotechnic compositions”. With his team, Mr. Cackett built up the knowledge on UK fuel/oxidant mixtures and how to apply their properties to meet increasingly difficult military requirements. Since the First World War these compositions were detailed and registered in the Superintendent of Research (SR) Composition Book. These “SR Compositions” were widely used by many NATO countries.

In 1940, following the outbreak of the Second World War, the pyrotechnics research group was evacuated from Woolwich to the grounds of Tondu House in South Wales. This was situated near to the military ordnance production factory at Bridgend. At this time Tondu was known as the Armament Research Department (ARD) and was controlled by the Headquarters Establishment at Fort Halstead, near Sevenoaks in Kent

In about 1957, the pyrotechnics facilities at Tondu were moved to Langhurst near Horsham, Sussex. Initially, Mr. Jack Cackett was the senior scientist in charge of the pyrotechnics team, which was made up of very experienced scientific and technical staff, who had transferred with him from Tondu. The research facility was an outstation of Fort Halstead, which in February 1962 was called the Royal Armament and Research Development Establishment (RARDE).

At Langhurst the pyrotechnic facilities and supporting scientific, engineering and technical staff were increased in order to meet the complex technical requirements for pyrotechnics in modern warfare. It was at Langhurst that Mr. Cackett wrote his book titled *Monograph On Pyrotechnic Compositions* originally classified to a restricted circulation but is now unclassified. The date of this publication is January 1, 1965.

During 1976 and 1977 Langhurst was closed down and all the pyrotechnic research and development facilities were transferred to RARDE, Fort Halstead.

During 1993, RARDE, along with other UK research establishments became the Defence Research Agency (DRA). In 1996, DRA became the Defence Evaluation Research Agency (DERA). In April 2001 two organizations were formed from

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<sup>11</sup> Dr. Tony Cardell OBE provided these details. He joined Mr. Jack Cackett’s team at Langhurst in 1962 and worked on UK pyrotechnic research and development through to his retirement from QinetiQ in 2004.

DERA. One is the Defence Science and Technology Laboratory (DSTL), which is part of the Ministry of Defence and the other is the public limited company, QinetiQ.

## History Of Navy Pyrotechnics Evolution

### An Interlaced Account of My Pyrotechnics Career at Crane

Prior to and during World War I, private contractors did nearly all pyrotechnic manufacturing and development work for the Army or Navy. During World War I, the Navy had a contract with the Ordnance Engineering Corporation, 120 Broadway, New York City, for the manufacture of 3, 4, 5 and 6-inch illuminating projectiles. That company held patents covering this type of projectile. The Ordnance Engineering Corporation began operations in an old farmhouse, located on what is now (1957) Sunrise Highway, Baldwin, Long Island, New York. A major fire destroyed the facilities after a few months of operation.<sup>12</sup>

In 1918, the Navy constructed a new plant in Baldwin, Long Island on Milburn Avenue for the Ordnance Engineering Corporation to use in the development and manufacture of illuminating projectiles. At the termination of World War I, the plant was taken over and operated by the Navy as the United States Naval Ordnance Plant (NOP), Baldwin, Long Island, New York. Its one product was illuminating projectiles until 1930.

Then, the plant was awarded a small contract to manufacture Naval aircraft parachute flares. Baldwin collaborated with the United States Naval Ordnance Laboratory (NOL), Washington, D.C., in the improvement and production of the Mark 4, Naval Aircraft Parachute Flare. Sixty units per week was the average schedule until 1939. From 1938 to 1942, the Marks 5 and 6 Aircraft Parachute Flares were developed and produced through the combined efforts of NOP Baldwin and NOL Washington.

NOL Washington was located in the Naval Gun Factory at the Navy Yard along the river in the SE section of Washington DC. NOL Washington did not become established in Silver Springs, White Oak MD until 1943. The latter became known as NOL Silver Springs and, today, is better known as NOL White Oak. (About the year 2000, it was closed by BRAC)

The working force for the Baldwin Plant was reduced to as few as 125 persons shortly after 1930. Private manufacturers were doing some development and manufacturing of pyrotechnics, but the quantities were small. The status of naval pyrotechnics as World War II began was similar to the status of military pyrotechnics at the beginning of World War I: somewhere between lousy and terrible! The demand for pyrotechnics was much greater and more exacting during World War II than during World War I because of the improved implements of warfare.

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<sup>12</sup> Morecock, William R. and George A. Platz, Jr. *Naval Pyrotechnics Development 1957*, prepared for NAD Crane. Some of the early information was extracted from this document. AD0003349.

Expansion had to be great. Contracts were let with companies who had no experience in this field. Experienced people had to be spread thinly over the industry to form nuclei for production units. Substitute materials had to be tested and authorized. Old units had to be improved and new units had to be designed. The production capacity of the Baldwin Plant was increased 900% from 1939 to 1942.

In the 1930's and 1940's, pyrotechnics development was assigned to the Naval Ordnance Laboratory, Washington DC. When NOL Silver Springs was established in 1943, the pyrotechnic development effort was transferred there. At NOL Silver Springs, Mr. Bernie White, Mr. Louis LoFiego, Mr. Dean Jensen, Mr. Roscoe Dwiggin, and others, did pyrotechnics development. They worked on projects sponsored by the Bureau of Ordnance (BuOrd) Washington, DC. NOL White Oak had laboratory facilities but only limited capability to build developmental and demonstration pyrotechnic test items.

BuOrd was located in "temporary" buildings built in World War I in Washington DC on the NW end of the Mall, just North of the Reflecting Pool. Also located in the vicinity, just to the South, were temporary World War II buildings occupied by BuAir and others. BuOrd had counterpart Bureaus such as BuAir, BuShips, BuDocs, BuMed, etc. BuOrd had charge of all ordnance including all Naval pyrotechnics. BuOrd section Ma3-b was the production-oriented group. Ma3-b later moved to NAD Crane to become NAPEC, Naval Ammunition Production Engineering Center, headed up by Mr. Art Maas. The Re2-a section of BuOrd sponsored research and development and ReW3c was the Pyrotechnic group of BuOrd. BuOrd moved to Crystal City, Arlington VA about 1962-3 when the old buildings on the Mall were torn down.

In 1940, the Bureau of Ordnance (BuOrd) decided to build a new pyrotechnic plant of larger capacity than at Baldwin at the Navy's newly constructed East Coast Ammunition Depot, Burns City, Indiana. At this location, the Navy was building facilities to load, renovate, and store naval gun ammunition such as the 3/50, 5/38, 6/47, and 16 inch projectiles and associated cartridges, bombs, torpedo warheads, depth charges, naval mines, and other conventional ammunition categories but not munitions containing propellants such as rockets. This depot was later renamed U. S. Naval Ammunition Depot (NAD), Crane, Indiana. A plan had existed for years to construct a new Star Shell Plant (illuminating projectiles were known as Star Shells) at the Naval Powder Factory, Indian Head, Maryland. That plan was jettisoned and the new Pyrotechnic plant was built at NAD Crane. Mr. William Russell Morecock, aka Russ, Mr. Jim Palladino and a few others came from Baldwin to run and staff the new pyrotechnic plant. Mr. Morecock was the Master Mechanic of the new operation, which today (2002) is the fenced in area near Building-120 (B-120). He also was the Master Mechanic of the Baldwin plant. He claimed to have had a hand in the design and layout of the new plant at Crane.

The Pyrotechnics Production Division of the Ordnance Department at NAD Crane, BuOrd, NOP Baldwin, and NOL Washington cooperated in the research and development of new pyrotechnics and the improvement of old pyrotechnics during World War II. After the war, NOP Baldwin was deactivated, practically all-private manufacture of pyrotechnics was discontinued, and NAD Crane's pyrotechnic production personnel staff was reduced to about 100 employees.

Mr. LoFiego writes that in 1947, the Navy planned to close the Pyrotechnic Production Plant at NAD Crane, which manufactured pyrotechnic items. He states "we" were able to convince the Navy to maintain these facilities. This was accomplished by using development funds to keep the key people who had years of experience in manufacturing pyrotechnics. As an example, the design work for a new illuminating projectile was accomplished at NOL Silver Springs and the prototypes were fabricated by NAD Crane Ordnance Department. Not losing these key individuals proved to be very fortunate for the USA during the Korean War.

Many World War II pyrotechnic items showed exceptionally poor performance ability after two or more years of storage. The Navy also appreciated the necessity of new designs for pyrotechnics to keep pace with aircraft that fly higher and faster and submarines that descend deeper. These requirements resulted in the Navy's instituting a research and development program for existing and new pyrotechnic items. Much of this work after World War II was carried out in collaboration with NOL Silver Springs and a limited number of private contractors first by the Production Division of the NAD Crane Ordnance Department until about 1951 and then by the Research and Development Division (R&D Div) of the Ordnance Department at NAD Crane until mid-1956. By this time, liaison was well organized between those groups, which use pyrotechnics, and the groups that design and manufacture pyrotechnics. The Bureau of Ordnance established budgets and planned projects to keep pyrotechnics abreast of the other tools of war that were being devised.

Before NAD Crane existed, NOL Washington got support from NOP Baldwin. When NOL Silver Springs and NAD Crane came into existence about the same time, NOL Silver Springs came to the NAD Crane Pyrotechnic Production Plant for support, first directly to Mr. Russ Morecock in the production plant and later to the R&D Division of the Ordnance Department at NAD Crane. Then when the Research and Development Department was established at NAD Crane in 1956, NOL Silver Springs received pyrotechnic design support from NAD Crane's new Research and Development Department.

NOL Silver Springs would come to NAD Crane by work request to get models and test units made to their designs during the early 50's (the Korean war era) and perhaps earlier. Mr. Glen Casey, Jr. known only as "Casey", pyrotechnics tool and die maker in the pyrotechnics plant, worked with Mr. Bernie White during his visits to NAD Crane to work out the details. The units or components were sent to NOL

for test. After testing, the cycle repeated again and again. This effort was supported at NAD Crane by a small R&D Division of the Ordnance Department, which was made up of about 6-8 Navy Ensigns and LTJG's headed by a reserve LCDR Austin Behlert USN who reported to the Ordnance Officer CDR John Ela USN. The Commanding Officer at that time was CAPT Eugene C. Rook USN. The pyrotechnics development and the NOL work was administered and directed by personnel of the Pyrotechnics Division. These persons worked with Mr. Russ Morecock and his Pyrotechnics Plant personnel to get the work done.

Bernard E. Douda was one of the Navy Ensigns sent to NAD Crane in September 1952 to work in the Pyrotechnics Division of the NAD Crane Ordnance Department. Others were: Mr. Joe Hammond, Mr. Bob Mariman, Mr. Roger Struck, Mr. Dick Randall, Mr. Bruce Butrym, Mr. Jim O'Brian, and Mr. John Dimmer. Mr. Hammond eventually became the administrative assistant to the Ordnance Officer. Mr. Dimmer engineered the production set-up and initial operation of the Plaster Load Facility in Building 2084 to fill warheads with an inert material for training use. Mr. O'Brian was our Explosive Ordnance Disposal Officer (EOD) assigned to run the EOD Demolition area. Mr. Butrym hooked up with the Special Projects (SP), ADM Rickover area, converted to regular Navy, and eventually achieved Captain's rank and, as his last duty station (I think), served as the Commanding Officer of the Navy Weapons Station (NWS) at Charleston, SC.

Trying to conduct developmental projects remotely from NOL White Oak was cumbersome. NOL White Oak was not very interested in the small amount of money, which pyrotechnics brought in. By this time (about 1954) Mr. LoFiego transferred from NOL White Oak to BuOrd to head up the pyrotechnics group there. Mr. Stan Fasig, a young engineer and Mr. Phil Smith (aka PJ) started to work at NOL White Oak, both on the same date. Mr. Ray Szypulski also was an NOL employee. NOL White Oak and BuOrd chose to move pyrotechnics R&D to Crane. To do this, they set up 19 billets at NAD Crane. With the support of Command and the Civilian Personnel Office, Mr. LoFiego came to NAD Crane for a week. He and then LTJG Douda, using NOL White Oak Position Descriptions (PD's) for samples, wrote the 19 PD's for the new NAD Crane R&D Department. Staffing started in late 1955 and early 1956. Mr. LoFiego later left government service to join the Bermite Powder Company in Saugus CA where he had a senior position, such as General Manager. Later, Mr. Fasig and Mr. Smith transferred to NAD Crane to fill positions in the new R&D Department.

In April of 1956, a Pyrotechnics Research and Development Department was established at NAD Crane for conducting all new pyrotechnic design through the prototype production for evaluation (PPE) stage. In this stage, new designs are subjected to a "dress rehearsal" production and the design or tooling are altered to achieve a product which will function to specifications and can be fabricated by conventional methods of manufacture. In today's terminology, we might think of the PPE stage as a late phase of Engineering Manufacturing Development (EMD) or an early phase of Limited Rate Initial Production (LRIP).

Mr. Victor Willis, then at Aerial Products Company, Elkton MD was chosen by Mr. Russ Morecock and Crane's Command as the first Pyrotechnics Research and Development Department Director of NAD Crane. Soon to follow Mr. Willis from Aerial Products was Mr. Ben Harkness. While still in the military, LTJG Douda was assigned to head up the Chemical Engineering Division of the R&D Department. In May 1956, LTJG Douda was released from the military and continued in the job as a civilian. Mr. Phil Cornwell, a Mechanical Engineer, was hired from Fabricast in Bedford, Indiana, a GM foundry operation. Mr. Stan Fasig was soon hired as the Mechanical Engineering Division head and very soon befriended Mr. Willis and moved into his office to become the Deputy Director. Mr. Phil Smith had transferred from NOL White Oak to BuOrd and then was hired by NAD Crane in early 1960 to form an Evaluation Division. Mr. Phil Cornwell became the Mechanical Engineering Division head. Mr. Charlie Connor headed the Documentation Group, of which Mr. Noble Wittenmeyer and Mr. Paul Scott were senior members. Mr. Wittenmeyer was a draftsman and Mr. Scott did a lot of design work as a draftsman. Mr. Jerry Kemp hired in as a Mathematician and soon headed the Math/Statistics Division. To this nucleus of staff came the duties of pyrotechnics development for the Navy. By 1958, NOL, White Oak had phased out of pyrotechnics development completely.

The R&D Department set up offices in the upper deck of Building 38 about late 1955, had no lab space there, and thus had to use the facilities of the pyrotechnics production plant for prototype operations, both mechanical and chemical. After about two years, Building 198 and Building 2540 were made available for the R&D Dept. (estimate 1958-9).

Several devices the R&D Department personnel were working on in the early 50's (about 1953) were the Mk 7 Mod 2 Marine Location Marker, the Mk 5 Mod 4 Marine Location Marker, Submarine Emergency Identification Signal (SEIS), and others. They were working on improved models of these devices. The Mk 25 Mod 0 Marine Location Marker came out of this effort about 1958.

About 1955, a red phosphorus (RP) production capability was built inside the pyrotechnics plant area. Mr. Morecock was still the Master Mechanic. He later retired about 1956 with severe health difficulties. LTJG Douda was Pyrotechnics Officer, assigned by CDR John Ela, to oversee the pyrotechnics operation for the Ordnance Officer. The RP area had many daily fires, mainly in the mixing and pressing operations. Three to six fires per 24 hours were not uncommon. LTJG Douda had the assignment of chasing the fire engines day and night. As we learned how to handle RP safely and improved the processes and procedures, fire and injuries diminished to a rarity.

About 1957-8, NOL White Oak and BuOrd wanted a second source for thermal battery production, then being produced by Eureka Williams and Eagle Pitcher. We visited the plant to learn how to build the battery and proceeded to build a thermal battery production line inside Building 2698. Some operations were technically

difficult because of the need to operate at about 4-5% relative humidity and the need to control the energy of the heat paper very closely. A lithium compound, which was extremely hygroscopic, was a major component of the heat paper. It required very low humidity during processing. A Parr Bomb calorimetry room was set up to do the heat paper analysis. Mr. Clarence Gilliam conducted a lot of the heat paper calorimetric measurements.

During the Korean War period, pyrotechnics production and development was booming. BuOrd later reorganized to become the Bureau of Naval Weapons (BuWeps), and still later to reorganize and split to become Naval Air Systems Command (NAVAIR) and Naval Sea Systems Command (NAVSEA). These agencies started to assign NAD Crane pyrotechnics duties such as Cognizant Field Activity (CFA). We were assigned all NAVSEA pyrotechnics and most of NAVAIR pyrotechnics responsibilities. A block of research money flowed from the Office of Naval Research (ONR) to NAVAIR and NAVSEA for them to administer and direct toward their special interests. We eventually received some of these research funds from NAVAIR, administered by Dr. Hyman Rosenwasser. Exploratory development funds were distributed in a similar manner: in NAVAIR Mr. Dick Wasneski, Mr. Jerry Kovalenko, LCDR Hugo Hardt and others and in NAVSEA by Dr. Adolph Amster and Mr. George Edwards. OPN and hardware development funds were administered in NAVAIR by Mr. Ray Szypulski as Technical Agent for PMA-253/PME-107, the latter being the REWSON (electronic warfare) Office of the Naval Electronics Command (NAVELEX).

It was during most of the 1960's and the early 1970's that NAD Crane received research and development funds from NAVAIR. About mid-1960, non-infrared (IR) decoy funds started to go away both in NAVAIR and in NAVSEA. The NAVSEA emphasis was on pollution abatement and disposal. For about ten years, we developed processes for ecologically acceptable ways to dispose of all categories of pyrotechnics. Dr. Ken Musselman and Dr. Carl Dinerman did most of the exploratory work and Mr. Jim Short developed pilot plants for these processes for NAVSEA. By about 1972, except for the disposal work, NAVSEA was out of the pyrotechnics development business. NAVSEA was assigned the tri-service lead for energetic materials disposal and pollution abatement.

In the early 1960's, NAVAIR set up the Naval Weapons Station, (NWS) China Lake to administer the pyrotechnics exploratory block of funds. NAD Crane then had to obtain NAVAIR pyrotechnics development funds from NWS China Lake. The latter tended to favor funding their projects in preference to projects proposed by other activities. They were chosen for this lead, instead of NAD Crane, because they were a NAVAIR station and NAD Crane belonged to NAVSEA. NAVAIR could not see fit to appoint a NAVSEA station to administer their work. This lasted until about 1977. When the amount of funds had diminished to below a critical mass, NWS China Lake told NAVAIR they would get out of the pyrotechnics development business entirely. FY 77 was the last year which NWC China Lake controlled the

exploratory development funding block and by 1980 had quit the pyrotechnics business completely.

In the early 1950's, the Naval Ordnance Test Station (NOTS), China Lake had embarked on the development of a heat-seeking missile, later to become the Sidewinder, AIM-9 series. This effort was lead by Dr. William B. McLean. He eventually became the NOTS Technical Director. In addition, there was substantial activity in development of devices against which the Sidewinder could be tested. In the early period, long before there was a need to determine the effectiveness of the Sidewinder against airborne targets, target flares and tracking flares were needed to make it easier to test rockets and missiles. Early tracking flares were formulated to produce visible radiation for visible tracking, presumably because tracking technology in the infrared was non-existent. Under the leadership of Dr. George Handler at China Lake, infrared target and tracking flare development and later infrared decoy flare development work continued into the 1960's. Dr. Handler, Mr. Art Breslow, Mr. Ed Allen and others lead this work. Their team and laboratory dissolved about the time (1960) that NAVAIR appointed NWC China Lake as the pyrotechnics lead. Dr. Handler has retired, as has Mr. Breslow. Mr. Allen transferred to NAVAIR to work for Mr. Szypulski and then to NAD Crane for a short period.

About the same time period (1964-1975), the Vietnam War was in full swing. As mentioned earlier, pyrotechnics funds for non-decoy projects were terminated first in NAVSEA about 1973 and then by NAVAIR about 10 years later. This left infrared decoy work as the first and only priority. Non-decoy pyrotechnics continued as product improvement, malfunction investigations, and production support. The demand for infrared decoys during the Viet Nam war was critical. PMA-253 and Mr. Szypulski pushed hard to get infrared flares developed and tested. NWC China Lake received substantial funding for decoys in the mid- to late-1960's. Mr. Don Hazelton of NAD Crane became involved with Dr. Pierre St. Armand of NWC China Lake for the development of a weather modification expendable based on silver iodide. These were tested during the hurricane season to try to reduce the fury of the storm. The units were fitted into the photoflash dispenser. Mr. Hazelton used his experience with the weather modification expendables development and his contacts in PMA-253, NAVAIR, and at NWC China Lake to ease into infrared decoy development. With only modest funding from PMA-253 via NAVAIR (Szypulski), Mr. Hazelton prepared infrared decoy test units for test first at NAD Crane and then for air test at NWC China Lake. The start of production of the Mk 46 Mod 0 took place during 1968 at NAD Crane. In response to a May 1972 Fleet message from Viet Nam expressing an urgent need for infrared decoys, NWC China Lake took the N-35 propellant (MTV-also called composition PL9001), put it into the pyrotechnic pistol cartridge and made the Mk 50 Mod 0 decoy flare for the M8 Pistol. The decoys were tested for decoy effectiveness using the Redeye missile as a surrogate for the SA-7 threat missile. Two thousand infrared decoys were shipped to SE Asia in June 1972. A recommendation for release to unlimited production of the Mk 50

Mod 0 decoy flare was issued 30 October 1973. Production followed of 50,000 units at the Naval Ordnance Station (NOS) Indian Head MD.

During this time period, Mr. Douda was doing research for Dr. Rosenwasser of NAVAIR and also attending Indiana University studying for a PhD in physical chemistry. (1973). Also in this time period, the R&D Department had a Chemistry R&D group doing development, first during the period that NAVAIR funded Crane directly, then during the period that NWC China Lake managed the funds for NAVAIR as non-decoy work faded. Eventually, NWC abandoned pyrotechnics development leaving it mostly for NAD Crane. This covered the 1960's. About 1968, Mr. Szypulski was contemplating retirement and while visiting NAD Crane, tried several times to persuade Mr. Douda to transfer from doing research and development to taking over the coordination of the decoy work as technical agent for NAVAIR and PMA-253. He wanted to transfer the focal point for this from NAVAIR to NAD Crane by way of a Transition Agreement. In this way, he thought his efforts would be continued. In February 1976, Dr. Douda was appointed DAPM, Deputy Assistant Program Manager to NAVAIR to lead the decoy work. By this time, Mr. Hazelton had solidified himself and NAD Crane in the decoy business. As DAPM, and with Mr. Szypulski still in NAVAIR for about a year more, Dr. Douda was taught how to deal with NAVAIR and PMA-253, how the money was structured, and how to sell projects to PMA-253. Mr. Szypulski retired at the end of 1977 and went to North Carolina to help his son in business.

Crane proceeded to formulate long-range infrared decoy development plans and propose them to PMA-253. CAPT Don Mathews was in charge. Mr. Bernie Panella was the Deputy. Mr. Panella and CDR Walt Carlson were decoy flare proponents. CDR Carlson later was in charge of the ASPJ project and still later would form and head up a PMA for the ASPJ. Mr. Panella retired about 1979 to form his own Electronic Warfare (EW) Company, now known as Raven, Inc. The new Deputy (about 1979) was Mr. Tony Grieco, not a decoy flare proponent, who later would leave to take the top EW job in the Office of the Secretary of Defense (OSD) when Mr. George Nicholas retired. Dr. Bill Goodell came to PMA-253 from the Naval Research Laboratory (NRL) to head up the Electro-Optics (EO) efforts. For OPN funds, we worked in PMA with Mr. Stan Bender starting about 1970 with the guidance of Mr. Szypulski and later alone after Mr. Szypulski retired about the end of 1977. For development funds, we worked with CDR Carlson, now retired and operating his consulting company, and Mr. Panella in the early 1970's and later with Mr. Frank Daspit starting about 1977.

Several events made our job more difficult selling decoys to the Program Office. In the late 70's, Mr. Panella and CDR Carlson left. The Navy was reorganizing again. PMA-253 was separated from PME-107. Mr. Goodell died in a car crash about 1985. Mr. Tony Grieco became Deputy in PMA-253 (retired about 1 April 2002). About 1994, Mr. Bender left PMA-253, went to NOP-88 Requirements, and about November 1995, went to the Ballistic Missile Defense Office BMDO. Mr. Bill Rock took over for expendables in PMA-253 when Mr. Bender left. Of all the managers in

Washington DC, Mr. Bender was not only a strong proponent for infrared decoys but also was a staunch supporter of NAD Crane throughout the years.

With the many organizational and personnel changes in Washington DC, we at Crane often were left without experienced decoy flare proponents in PMA-253. The Viet Nam war was winding down and funds were being reduced correspondingly. The RF proponents of EW along with the EO supporters declared that flares were done and other technology would take over in a few years. This was in the late 70's. RADM Grady Jackson, now retired, a former head of PME-107, and later in OSD as the EW head, also was not a strong supporter of decoys. He too contended flares were done which is surprising since he was a navy pilot in Viet Nam. It seemed like everyone in the EW business had written off decoy expendables, perhaps motivated by their desire to get a larger share of the funds. Even with these handicaps, we were able to increase our PMA-253 budget for decoys from about 150K in 1970 to 3-4M in 1995.

Reorganizations continued in the exploratory development area as well. In about the mid-1980's, all EW development funds were taken from the Commands and given as a block to NRL by ONR. Non-decoy funds had disappeared earlier. NAD Crane now had to compete for air decoy projects with other claimants for the funds in the EW block. NRL has the lead for all ship decoy projects. The exploratory development budget for air decoys went to zero in FY2003.

In August 1994, Mr. Steve Norris was appointed the NAVAIR technical agent (Lead Commodity Engineer) for Infrared Expendable Countermeasures. At that time the Program Manager Air (PMA) responsible for this commodity was PMA-253, which later became PMA-272. As Mr. Norris took hold, Dr. Douda progressively relinquished his infrared decoy administrative duties to him. Also about 1994, PMA-272 split off the Electronic Warfare (EW) expendables acquisition group to form PMA-222 at the Naval Air Station, Jacksonville FL. In 1996, PMA-222 was absorbed back into PMA-272 in preparation for the relocation by 1 October 1997 of PMA-272 from Crystal City, Arlington VA area to the Naval Air Warfare Center, Aircraft Division, Patuxent River MD.

Written in 2002 by Bernard. E. Douda and edited in January 2008.



## Composition Designations

### The series designated PL (Pilot Lot)

The "NOTS Standard" infrared composition prior to the introduction of Viton® A was 54% magnesium gran -16, 30% Teflon® #1 600µm particle size, and 16% Kel-F® #10 wax. This was the standard prior to the introduction of the shock-gel process in 1959. The Kel-F wax composition has low tensile strength and exhibited an electrostatic sensitivity at the 50% point of 0.76 joules. The density, after fabrication into a grain, is only about 90% of theoretical.

PL 6010: Igniter composition consisting of 16% magnesium and 84% Teflon® #5 molding powder.

PL 6011: Igniter composition consisting of 66% magnesium and 34% Teflon® #5 molding powder.

PL 6012: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder and 5% sodium fluoride.

PL 6013: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder and 5% potassium dichromate.

PL 6014: Igniter composition consisting of 16.09% magnesium, 33.08% Teflon® #5 molding powder, 45.83% potassium perchlorate, and 4% potassium dichromate.

PL 6014A: Igniter composition consisting of 18.12% magnesium, 37.25% Teflon® #5 molding powder, 39.63% lithium perchlorate, and 5% potassium dichromate.

PL 6020: Igniter composition consisting of 25.13% aluminum, 69.87% Teflon® #5 molding powder, and 5% sodium fluoride.

PL 6022: Igniter composition consisting of 25.13% aluminum, 69.87% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6023: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6024: Igniter composition consisting of 11.98% boron, 83.02% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6025: Igniter composition consisting of 23.75% aluminum, 23.75% boron, 47.50% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

- PL 6026: Igniter composition consisting of 10% aluminum, 50% boron, 35% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.
- PL 6027: Igniter composition consisting of 5% aluminum, 85% boron, 7% Teflon® #5 molding powder, 1.5% sodium fluoride and 1.5% potassium dichromate.
- PL 6032: Igniter composition consisting of 5% aluminum, 18.13% boron, 7% Teflon® #5 molding powder, 66.87% lithium perchlorate, 1.5% sodium fluoride and 1.5% potassium dichromate.
- PL 6033: Igniter composition consisting of 66.4% thorium, 28.60% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.
- PL 6041: Igniter composition consisting of 9% magnesium, 33.39% zirconium, 44.97% Teflon® #5 molding powder, 9% lithium perchlorate, 3% potassium dichromate, and 9% lead fluoride. The zirconium is 50 to 100 mesh obtained from City Chemical Corporation.
- PL 6042: Igniter composition consisting of 9% magnesium, 21.53% titanium, 26.61% Teflon® #5 molding powder, 9% lithium perchlorate, 3% potassium dichromate, and 9% lead fluoride. The titanium is less than 325 mesh obtained from City Chemical Corporation.
- PL 6043: Igniter composition consisting of 9% magnesium, 27.31% molybdenum, 42.69% Teflon® #5 molding powder, 9% lithium perchlorate, 3% potassium dichromate, and 9% lead fluoride. The molybdenum is 200 mesh obtained from City Chemical Corporation.
- PL 6054: Igniter composition consisting of 45.32 zirconium, 49.68% Teflon® #5 molding powder, 2.5% sodium fluoride, and 2.5% potassium dichromate. The zirconium is less than 200 mesh obtained from Metal Hydrides, Inc.
- PL 6077: Igniter composition consisting of 50% magnesium, 25% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.
- PL 6078: Igniter composition consisting of 40% magnesium, 35% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

- PL 6079: Igniter composition consisting of 30% magnesium, 45% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.
- PL 6080: Igniter composition consisting of 20% magnesium, 55% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.
- PL 6081: Igniter composition consisting of 25% magnesium, 25% boron, 25% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.
- PL 6084: Igniter composition consisting of 60% magnesium, 15% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.
- PL 6085: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder, 2.5% sodium fluoride, 2.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.
- PL 6239: IR flare and ignition composition consisting of 54% magnesium (45-75µ), 30% Teflon® #7 (35µ), and 16% Viton® A. Another source states PL 6239 is an IR flare composition consisting of 54% magnesium gran 16, 30% Teflon® #5 (reground to 35µ), and 16% Viton® A.
- PL 6246: Underwater flare composition: 30.5% magnesium gran 16, 49.7% Teflon® #7, 16.3% Viton® A, 1% aluminum, 1% boron, and 1.5% sodium chloride.
- PL 6278: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #7 (35µ), 7.5% Teflon® #5 (300µ), and 16% Viton® A.
- PL 6279: IR flare composition: 54% magnesium gran16, 15% Teflon® #7 (35µ), 15% Teflon® #5 (300µ), and 16% Viton® A.
- PL 6280: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #7 (35µ), 22.5% Teflon® #5 (300µ), and 16% Viton® A.
- PL 6281: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #7 (35µ), 7.5% Teflon® #1 (600µ), and 16% Viton® A.

- PL 6282: IR flare composition: 54% magnesium gran16, 15% Teflon® #7 (35μ), 15% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6283: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #7 (35μ), 22.5% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6287: IR flare composition: 54% magnesium gran16, 5% Teflon® #7 (35μ), 12.5% Teflon® #5 (300μ), 12.5% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6288: IR flare composition: 54% magnesium gran16, 10% Teflon® #7 (35μ), 10% Teflon® #5 (300μ), 10% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6289: IR flare composition: 54% magnesium gran16, 15% Teflon® #7 (35μ), 7.5% Teflon® #5 (300μ), 7.5% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6290: IR flare composition: 54% magnesium gran16, 20% Teflon® #7 (35μ), 5% Teflon® #5 (300μ), 5% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6294: IR flare composition: 64% magnesium gran15 and 36% Viton® A.
- PL 6295: IR flare composition: 64% magnesium gran15, 20% Teflon®, and 16% Viton® A.
- PL 6296: IR flare composition: 64% magnesium gran16 and 36% Viton® A.
- PL 6297: IR flare composition: 64% magnesium gran17 and 36% Viton® A.
- PL 6298: IR flare composition: 64% magnesium gran17, 20% Teflon®, and 16% Viton® A.
- PL 6299: IR flare composition: 64% magnesium gran16, 20% Teflon®, and 16% Viton® A.
- PL 6309: IR flare composition: 54% magnesium gran 15, 30% Teflon® #5 (reground to 35μ), and 16% Viton® A.
- PL 6320: IR flare composition: 54% magnesium gran16, 30% Teflon® #7 (35μ), and 16% Viton® A. This is the "improved" formula that came about with the shock-gel process in 1959. It has an electrostatic sensitivity of 12.5 joules (no fires in 10 trials), is easy to extrude at temperatures ranging from 150F to 225F in a conventional double-base propellant extrusion press. Compression molding can also process the composition. The extruded forms can be machined, and have tensile strengths and elongation that withstand application forces.

- PL 6328: IR flare composition: 54% magnesium gran16, 30% Teflon® #1 (600μ), and 16% Viton® A. The density is 1.8 grams per cubic centimeter.
- PL 6353: IR flare composition: 58% magnesium gran16, 30% Teflon® #5 (300μ), and 12% Viton® A.
- PL 6364: IR flare composition: 50% magnesium gran16, 30% Teflon® #5 (reground to 35μ), and 20% Viton® A.
- PL 6365: IR flare composition: 50% magnesium gran16, 20% Teflon® #5 (reground to 35μ), and 30% Viton® A.
- PL 6366: IR flare composition: 50% magnesium gran16, 10% Teflon® #5 (reground to 35μ), and 40% Viton® A.
- PL 6367: IR flare composition: 60% magnesium gran16, 30% Teflon® #5 (reground to 35μ), and 10% Viton® A.
- PL 6368: IR flare composition: 60% magnesium gran16, 20% Teflon® #5 (reground to 35μ), and 20% Viton® A.
- PL 6369: IR flare composition: 60% magnesium gran16, 10% Teflon® #5 (reground to 35μ), and 30% Viton® A.
- PL 6370: IR flare composition: 70% magnesium gran16, 20% Teflon® #5 (reground to 35μ) and 10% Viton® A.
- PL 6371: IR flare composition: 70% magnesium gran16, 10% Teflon® #5 (reground to 35μ), and 20% Viton® A.
- PL 6373: IR flare composition: 54% magnesium (325 mesh), 30% Teflon® #5 (Reground to 35μ), and 16% Viton® A.
- PL 6377: IR flare composition: 58% magnesium gran16, 30% Teflon® #7 (35μ), and 12% Viton® A.
- PL 6378: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #5 (300μ), 22.5% Teflon® #7 (35μ), and 16% Viton® A.
- PL 6379: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (300μ), 15% Teflon® #7 (35μ), and 16% Viton® A.
- PL 6380: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #5 (300μ), 7.5% Teflon® #7 (35μ), and 16% Viton® A.

- PL 6381: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #1 (600μ), 22.5% Teflon® #7 (35μ), and 16% Viton® A.
- PL 6382: IR flare composition: 54% magnesium gran16, 15% Teflon® # 1, 15% Teflon® #7, and 16% Viton® A.
- PL 6383: IR flare composition: 54% magnesium gran16, 22.5% Teflon® # 1, 7.5% Teflon® #7, and 16% Viton® A.
- PL 6384: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #5 (300μ), 7.5% Teflon® #1 (600μ) and 16% Viton® A.
- PL 6385: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (300μ), 15% Teflon® #1 (600μ) and 16% Viton® A.
- PL 6386: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #5 (300μ), 22.5% Teflon® #1 (600μ) and 16% Viton® A.
- PL 6387: IR flare composition: 54% magnesium gran16, 12.5% Teflon® #5 (300μ), 12.5% Teflon® #1 (600μ), 5% Teflon® #7 (35μ) and 16% Viton® A.
- PL 6388: IR flare composition: 54% magnesium gran16, 10% Teflon® #5 (300μ), 10% Teflon® #1 (600μ), 10% Teflon® #7 (35μ) and 16% Viton® A.
- PL 6389: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #5 (300μ), 7.5% Teflon® #1 (600μ), 15% Teflon® #7 (35μ) and 16% Viton® A.
- PL 6390: IR flare composition: 54% magnesium gran16, 5% Teflon® #5 (300μ), 5% Teflon® #1 (600μ), 20% Teflon® #7 (35μ) and 16% Viton® A.
- PL 6392: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (reground to 35μ), 15% Teflon® #5 (300μ), and 16% Viton® A.
- PL 6393: A visual flare formula. 47% magnesium (200-300 mesh), 28% sodium nitrate, 15% Teflon® (600μ), and 10% Viton® A: Extruded.
- PL 6396: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (reground to 35μ), 15% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6397: IR flare composition: 54% magnesium gran16, 16% Viton® A, and 30% Kynar®. The latter is polyvinylidene fluoride.
- PL 6500: A visual flare formula. 47% magnesium (200-300 mesh), 28% sodium nitrate, 15% Teflon® (300μ), and 10% Viton® A: Extruded.

- PL 6501: A visual flare formula. 39% magnesium (200-325 mesh), 25% sodium nitrate, 32% Teflon® (600μ), and 4% Viton® A: Extruded.
- PL 6502: A flare formula consisting of 35% magnesium (200-325 mesh), 22.5% sodium nitrate, 29% Teflon®-1 (600μ), 3.5% Viton® A and 10% polystyrene beads. It is claimed that the addition of the beads converts the radiation from visible to the IR. This composition can be extruded.
- PL 6503: A high altitude ignition composition that sustains ignition at 150,000 feet altitude (1.1 torr). It consists of 54% magnesium (3-5μ), 30% Teflon® #1 (600μ), and 16% Viton® A.
- PL 6809: Illumination formula consisting of 56% magnesium (30/50 granular particle size), 35% sodium nitrate, and 4% Viton® A.
- PL 6842: Illumination formula consisting of 56% magnesium (gran 17), 37% sodium nitrate, and 7% Viton® A.
- PL 6920: IR flare formula consisting of 70% magnesium gran 16, 14% Teflon® #7, and 16% Viton® A, It is a very high output-short burning composition. A second formula was reported as 70% magnesium gran 16, 15% Teflon® #7, and 15% Viton® A as a composition capable of being extruded.
- PL 6920-1: IR flare formula consisting of 2.5% graphite added to a PL 6920 composition. Not good for extruding.
- PL 6920-2: IR flare formula consisting of 5% graphite added to a PL 6920 composition. Not good for extruding.
- PL 6920-3: IR flare formula consisting of 10% graphite added to a PL 6920 composition. This composition extrudes well.
- PL 6920G: IR flare formula consisting of 18% to 20% graphite added to a PL 6920 composition. Graphite is added to assist extrusion and regulate burning. This composition extrudes well. The grains burned faster than the 3 seconds desired. Ignition at 40,000 feet altitude is satisfactory.
- PL 7078: Similar to PL 6920G but contains 63% magnesium.
- PL 8005: IR flare formula consists of 54% magnesium, 30% Teflon®, 4% Viton® A, and 12% Krayton 101 binder. The latter is a polybutadiene-styrene copolymer.

PL 9000: Early variant: The IR formula consists of 63% magnesium, 13.5% Teflon®, 13.5% Viton® and 10% graphite. Dry blending the graphite with the PL 6920 extrusion powder makes this formula. Used in Ex 49 Mod 0 and Mk 49 Mod 0 decoy flare grain.

PL 9000: Later variant: The IR formula consists of 63% magnesium, 13.5% Teflon®, 13.5% Viton® and 10% graphite. This formula is made with the graphite being added to the PL 6920 extrusion powder slurry before shock precipitation of the binder.

PL 9001: In August 1973, the Naval Air Systems Command (NASC) issued a material specification for an IR flare composition consisting of 54% atomized magnesium, 30% Teflon® and 16% Viton® A. The heat of explosion for this mixture is about 1450 calories per gram. The specification covers a precipitated powder mixture called Type I and a mixture used to make extruded grains called Type II. Type I flare mixture is used in ignition trains. The Type II mixture is used as the main charge in igniters and flares. Composition PL 9001 is similar to N-35 Propellant in formulation but allows a wider magnesium particle size range.

**CT-070 Flare Mix:** This is an infrared flare mix. It is made up of composition PL 6920, a very high output-short burning composition.

**Formula 256 for Cast Flare:** This is a formula to make a cast grain from 46% magnesium, 28.9% ammonium perchlorate, 1.4% Viton® and 23.5% Sylgard® 182.

**FW-306 Flare Composition:** This is an infrared composition used in the ALA-17 flare consisting, in parts by weight, of 54 parts magnesium, 46 parts Teflon®, and 2.6 parts nitrocellulose.

**SI-119 Infrared Flare Composition:** This is a composition developed at Picatinny Arsenal that radiates in the 1.8µm to 2.8µm bandpass region. It is reported to be unaffected by increasing altitude up to 60,000 feet, when it tapers off slightly. The constituents are molybdenum trioxide, chromic oxide, and zirconium.

## Other Designations

**A-1A Gasless Ignition Powder:** This powder is under cognizance of the Naval Air Systems Command. It consists of 65% zirconium powder, 25% ferric oxide, and 10% diatomaceous earth.

**CT-0025 Ignition Composition:** This is an ignition composition consisting of 9.8% boron, 88.2% barium chromate and 2.0% zinc stearate. It exhibits an electrostatic sensitivity of 0.596 joules, a 10-fold decrease in electrostatic sensitivity as compared to the FD-30 ignition composition.

**CT-144 Igniter Mix:** This is an igniter mix used to make the pellet that ignites the grain in the EX 49 Mod 0 decoy flare. It also is used as an igniter mixture, which is painted on both ends of the N-35 propellant used in the Mk 50 Mod 0 decoy flare. This igniter mix also was planned for use to ignite composition PL 9000 in the EX 51 Mod 0 flare.

**D-16 Delay Powder:** D-16 is a gasless manganese-type delay composition developed at NOL White Oak about the mid 1950s. It consists of manganese, barium chromate and lead chromate and is described in specification Mil-M-21383. Variants of the formula allow tailoring of the burning rate through the range of 3.7 to 13.5 seconds per inch.

**F-33B Gasless Ignition Powder:** F-33B powder is under the cognizance of Picatinny Arsenal. This mixture consists of 41% zirconium powder, 49% ferric oxide, and 10% diatomaceous earth.

**FA878 Igniter Mix:** (FA=Frankfort Arsenal) This igniter mix consists of 32.5% zirconium (one-grade), 7.5% zirconium (another grade), 20% barium nitrate, 20% lead dioxide, and 20% pentaerythritol tetranitrate (PETN).

**FD-30 Igniter Composition:** This composition consists of 10% boron and 90% barium chromate. It exhibits an electrostatic sensitivity of 0.0528 joules.

**FW-210 Ignition Mix:** This mixture consists of manganese dioxide and zirconium. The mix is effective at high and low altitudes.

**H-9 Propellant:** The 1948 version of the FFAR rocket contains the H-9 propellant.

**K Composition:** This is an improved igniter "K" composition containing dichromated 50/50 Mg/Al alloy or 65/35 Mg/Al alloy instead of unalloyed magnesium. Dr. Hart, Picatinny Arsenal, developed this composition about 1944.

**N-4 Propellant:** The N-4 propellant replaced the H-9 propellant in the FFAR rocket in the fall of 1950. The N-4 Propellant introduced a low temperature ignition problem with the Mk 125 Mod 0 igniter then in use.

**N-35 Propellant:** The N-35 propellant consists of magnesium-Teflon®-Viton® and is similar to composition PL 9100 in formulation but requires a narrower magnesium particle size range. It is 1.4 inches in diameter by 2.4 inches long and is used in the Mk 50 Mod 0 decoy flare in 1972. It is relatively insensitive. It has an 8-point internal star, the points of which are shaved off for greater surface. Ignition mix CT-144 is painted on both ends.

**Rapac Mix Ignition Composition:** This is a first fire mixture that consists of zirconium, lead dioxide and polymethylvinyltetrazole (PMTV) the latter being dissolved in methylene chloride. It is used as a flare grain coating. The Rapac mix is electrostatic and friction sensitive. It is used in the EX 46 Mod 0 decoy flare and its predecessor the NOTS Model 400A decoy flare. Reportedly, it is superior to FD-30 ignition composition.

**Z-2 Heat Paper:** This is an inorganic paper that is impregnated with zirconium-barium chromate.

## Squibs and Thermites

**NOTS Model 4 Squib:** The NOTS Model 4 squib might have been the forerunner to the Mk 1 Mod 0 squib.

**NOTS Model 39 Pyrogen Squib:** The development of this squib resulted from a need for a reliable technique for electric ignition of flares at high altitude, up to 190,000 feet. This is a self-contained ignition device with a grain and nozzle inside of a hermetically sealed case that is capable of igniting flares without aid from additional materials. It is fabricated in the same external configuration as the Mk 1 Mod 0 squib. The NOTS Model 39 pyrogen squib reliably ignites 1-inch diameter test flares at simulated altitudes to 190,000 feet (0.25 torr). Investigators considered the use of a bridge wire with the Mk 2 squib. The latter has characteristics to reduce electromagnetic radiation hazards. (HERO).

**NOTS Model 39A Pyrogen Squib:** This squib is installed in the NOTS Model 726B flare to get better high altitude ignition.

**Mk 1 Mod 0 Squib:** This squib is installed in 2.75-inch rockets. It also is used to ignite the NOTS Model 702 flare series.

**Mk 2 Squib:** In 1964, Picatinny Arsenal improved this squib to make it HERO safe. This also is implied in remarks regarding the development of the NOTS Model 39 pyrogen squib. The squib is rated 5-amp.

**Mk 3 Squib:** No data located.

**M35 Squib:** McCormick Selph made this squib. Universal Match Corporation used it during flare composition evaluations.

**M37 Squib:** Universal Match Corporation used this squib during flare composition evaluations.

**F-ND Model 706 Squib aka USF Model 706 Squib:** This squib manufactured by Flare Northern Division of the Atlantic Research Corporation or U. S. Flare Division of the Atlantic Research Corporation is used in the W137 tracking flare, the W211 flare, and the W211 target flare.

**Mk 131 Mod 0 Impulse Cartridge:** This cartridge is used to eject the Mk 49 Mod 0 flare from its dispenser. Impulse cartridges are sometimes called squibs.

**Model 194 Pot:** This is a thermite filled carbon crucible that weighs 16 pounds. Six of these pots are installed on the F6F-5K drone. Starting in 1958, the F6F-5K drone was replaced by the Ryan KDA-1 Firebee drone powered by one Continental J69 turbo-jet engine. The Firebee drone is augmented with two clusters of the NOTS Model 702A flares on each wing tip, the Model 194 pot being too heavy.



## Identification of Some Additional Flare Related Devices

**AN/ALE-11 Dispenser:** This dispenser has a pneumatic ejection system with two rows of infrared flares or chaff. The dispenser is 10 inches wide by 6 inches high by 4 feet long. The Flare Northern rectilinear castable flare is designed for use with this dispenser.

**AN/ALE-14 Countermeasure Flare Ejector:** The ALA-17 flare is dispensed from the AN/ALE-14 countermeasure flare ejector mounted in the B-47 bomber and the B-52 bomber. The RITA-II flare fits this dispenser.

**AN/ALE-18 Pneumatic Dispenser:** The Mk 43 Mod 0 flare fits this dispenser, as does the NOTS Model 715 flare.

**AN/ALE-20 Ejector Set:** Originally, this dispenser set was developed for the B-52 aircraft. This assembly contains eight launch tubes with two stacked flares in each tube. The QRC-127 flare is compatible with this dispenser as is the RITA-II flare.

**AN/ALE-25 Dispenser:** This is a pod mounted dispenser, 154 inches long by 20 inches in diameter accommodating twenty ADR-9A countermeasure rocket systems. The pod is mounted between the engines of the B-52 late model series bomber and weighs 295 pounds unloaded.

**AN/ALE-28 Ejector Set:** Originally, this dispenser set was developed for the F-111 aircraft. It dispenses the RR-119 decoy flare. It can carry 13 of the 2-inch thick flares in each of two channels.

**AN/ALE-29A Chaff Flare Dispenser:** This dispenser has 30 cylindrical chambers into which the chaff and flare cartridges are loaded.

**AN/ALE-29/39 Chaff Flare dispenser:** Goodyear Corporation developed this dispenser set for use on Navy aircraft such as the F-4 and F-8.

**AN/ALE-33 Chaff Flare Dispenser:** Lundy developed this dispenser. It was used to dispense the MK 42 Mod 0 flare and the NOTS Model 733 flare.

**AN/ALE-37 Chaff Flare Dispenser:** This dispenser has 240 cylindrical chambers into which the chaff and flare cartridges are loaded.

**AN/ALE-39 Chaff Flare Dispenser:** This dispenser has 60 cylindrical chambers into which the chaff and flare cartridges are loaded.

**AN/ALE-40 Chaff Flare Dispenser:** This dispenser, made by Tracor, accepts three different rectilinear flares in the configuration of 1 inch by 1 inch by 8 inches, 1 inch by 2 inches by 8 inches, and 2 inches by 2.5 inches by 8 inches.

**LA-307A Photoflash Cartridge Dispenser:** The manufacturer of this dispenser is Lambert Engineering, Inc., Saint Louis, Missouri. This cartridge ejector is used with the M-112 photoflash cartridges and the QRC-353 (T)-1 Type I Flare.

**LA-308A Photoflash Cartridge Dispenser:** The manufacturer of this dispenser is Lambert Engineering, Inc., Saint Louis, Missouri. This cartridge ejector is used with the M-123 photoflash cartridges, the QRC-353 (T)-1 Type II Flare and the MJU-2/B decoy flare. It is internally mounted in the aft end of RF-4 aircraft and has been installed on other aircraft.

**M-130 Flare Dispenser:** This is an Army dispenser which is capable of firing flares with a 1 inch by 1 inch by 8 inch format. The M-130 dispenser can dispense either 30 decoy flares or 30 chaff cartridges.

**Model 30-0011-2 Chaff Dispenser:** This dispenser made by Lundy is electrically operated. The RR-72 chaff and the NOTS Model 733A target flare are compatible with this dispenser.

**USAF 669A Phase I dispenser:** This is an Air Force dispenser, built by Tracor, which is compatible with rectangular configured infrared flares such as the RR-115 flare, the RR-119 flare or the UM-111 flare. The flare format is 2-inch by 2 inch by 5-inch.

**XM-126 Dispenser:** The XM-126 nomenclature is believed to be that assigned to the dispenser that had been developed for the Army XM-196 mini-flare by ECOM at Fort Monmouth.

**NOTS Model 104-G Rocket Flare Head:** This is a flare head for a 5.0-inch HVAR motor. It was developed by NOTS in 1952 and contains illuminating composition. It also contains a pyrotechnic delay instead of a mechanical delay. It is the forerunner of the Mk 26 Mod 0 rocket flare head.

**NOTS Model 108A Rocket Flare Head:** NOTS Inyokern developed this rocket flare head about 1951.

**NOTS Model 113A Rocket Flash Head:** NOTS Inyokern in 1952 developed the NOTS Model 113A 5-inch flash head for the HVAR rocket. It provides a brilliant flash about 0.067 seconds duration at a given time after the rocket leaves the launcher, thereby marking one point on the rocket's trajectory. The 5-inch flash head is an outgrowth of the 2.75-inch FFAR flash head. It consists of a plaster loaded MK 6 Mod 1 five-inch head, the fuze unit of the 2.75-inch flash head, and a canister tube of flash powder.

**Mk 26 Mod 0 Rocket Flare Head:** This head is for 5.0-inch FFAR Zuni rocket, the 5.0-inch HVAR, and 5.0-inch high performance air to ground (HPAG) rocket. It contains illumination composition. It is the forerunner of the Mk 33 Mod 0 rocket flare head.

**Mk 33 Mod 0 Rocket Flare Head:** This head, also containing illumination composition, is an improvement of the Mk 26 Mod 0 rocket flare head. It was designed and developed at NOTS prior to 1964. The flare is ejected from the rocket head. The flare produces 1,000,000 candela for 90 seconds. The flare ejection from the rocket head is base first with a maximum descent rate of 15 feet per second. The goal is 95% reliability and proper function at minus 65 and +165 F. NOL White Oak developed a 14 second delay fuse for the rocket flare head. The delay fuse was first designated as XW-128B flare fuse and later as the Mk 193 Mod 0 flare fuze. Until the NOL fuze became available in 1960, the NOTS Model 553A flare igniter was used for head separation and flare ignition.

**NOTS Model 553A Flare Igniter:** This igniter is installed in the Mk 33 Mod 0 rocket flare head for head separation and flare ignition.

**NOTS Model D634 Igniter:** This is the improved modified igniter used in the FFAR rocket after Mr. Eckert of NOTS changed the charge to fix a low-temperature ignition problem with the M125 Mod 0 igniter. The charge is 8-grams of black powder and 2 grams of vinyl-coated magnesium powder. The NOTS Model D634 igniter had ignition failures below minus 40F. By May 1951, a redesigned igniter was developed called the NOTS Model D639 igniter later to be designated the Mk 125 Mod 2 igniter.

**NOTS Model D639 Igniter:** NOTS Model D634 igniter had ignition failures below minus 40F. By May 1951, a redesigned igniter was developed called the NOTS Model D639 igniter later to be designated the Mk 125 Mod 2 igniter. The NOTS Model D639 igniter is installed in the FFAR rocket. The charge is 8-grams of black powder and 2 grams of vinyl-coated magnesium powder.

**Mk 125 Mod 0 Igniter:** This igniter in the FFAR rocket contains the N-4 propellant, which introduced a low-temperature problem in the igniter. An improved modified igniter is designated the NOTS Model D634 igniter.

**Mk 125 Mod 2 Igniter:** This igniter in the FFAR rocket is the improved design by Mr. Eckert of NOTS, which is the successor to the NOTS Model D639 igniter. The Mk 125 Mod 2 igniter contains a charge consisting of 8-grams of black powder and 2 grams of vinyl-coated magnesium powder.

**Mk 2 Mod 0 Ignition Element:** This ignition element is used in the bore-safe Navy mini-flare.

**M39A1 percussion primer:** The Mk 50 Mod 0 flare uses this primer.

**Mk 154 Mod 0 Stab Primer:** This is the tentative designation for the NOTS Model 668A stab primer.

**NOTS Model 668A Stab-initiated Primer:** This primer is installed in the NOTS Model 733A target flare. The NOTS Model 668A primer was tentatively designated the Mk 154 Mod 0 stab primer. This primer was released to the NOTS Engineering Department in September 1962.

**NOTS Model 751A Flash Signal:** This is the flash signal that indicates fuze actuation for the Sparrow I missile.

**Mk 1 Mod 0 Flash Signal:** This is a Flash Signal for the Sidewinder exercise head.

**Mk 2 Mod 0 Flash Signal:** This is a Flash Signal for the Sidewinder exercise head.

**Mk 36 Mod 0 Signal, Flash, Guided Missile:** This is a flash signal for the Sparrow II missile to indicate fuze actuation.

**Mk 37 Mod 0 Signal, Flash, Guided Missile:** This is a flash signal for the Sparrow III missile to indicate fuze actuation. Researchers in the Pyrotechnics and Fuze Branches at NOTS developed and tested it about 1957.

**Mk 193 Mod 0 Flare Fuze:** This is a 14-second fuze developed by NOL White Oak, which is installed in the Mk 33 Mod 0 rocket flare head. It earlier was designated the XW-128B flare fuze.

**XW-128B Flare Fuse:** This fuse designation evolved into the Mk 193 Mod 0 flare fuze.

**RR-72 Chaff Cartridge:** This chaff cartridge was designed for use in the Lundy Model RC17-101 mechanically operated miniature chaff dispenser and the electrically operated Lundy Model 30-0011-2 chaff dispenser.

## Potpourri

### **Prognosis in 1968 of Decoy Flare Demise:**

Mr. B. Richard Case of General Dynamics Corporation, Fort Worth, Texas, during his presentation at the annual IRIS IRCM meeting on "Modern Flare Measurement and Data Reduction Methods" made the following statement about the demise of flares. He first says, "If anyone ever had the opportunity to witness the ground testing of a modern flare, I'm sure you can share my reluctance to refer to these devices as "passive" countermeasures. However, since some distinction had to be made between pulsed infrared jammers and flares, the flares were so classified." He goes on to say, "There are those who sounded the death knell for passive IRCM. They say that flares are fast becoming obsolete and that the "active" IRCM will soon provide the needed protection. The facts, however, do not support this conclusion. We have seen evidence during this symposium that pulsed jammers are still in the embryonic stage and struggling for survival. Flares, on the other hand, are just maturing." He concludes by saying, "The point that should be made is that we stand on the threshold of an era in which flares will play a commanding role. Conservative estimates place flares as the primary defense for the next 5-7 years and as a sound secondary defense for another decade afterwards".

### **Square vs. Round Holes and the AN/ALE-40 Chaff/Flare Dispenser**

About 1969-71, the Air Force had no chaff capability in their fighter size aircraft except the RF-4C fighter, which carried some chaff in their Lambert LAU-308A photoflash flare dispensers. Most Air Force aircraft going to North Viet Nam during that time period dispensed chaff bundles, which had been packed in their speed breaks. This gave them a one-shot protection capability. With knowledge of this limited capability Tracor, Inc., headquartered in Austin Texas, submitted an unsolicited proposal, which lead to a contract award for the development of an advanced pyrotechnic dispensing program. This exploratory development program covers a period from 17 Nov 1969 through completion 15 July 1970. The work was performed as an Air Force Avionics Laboratory Project under the direction of Captain Richard D. Hunziker of the Electronic Warfare Division. Mr. Bennie A. Shupe managed the program at Tracor. The Tracor project engineer was Mr. Robert C. James. Tracor's engineers accomplishing the work were Mr. Rod Johnson, Mr. Willie Laubach and Mr. Sidney Lanier. As a vehicle to test their experimental square and hexagonal chaff units, Tracor investigators built experimental dispenser modules with square and hexagonal holes. They wanted to compare chaff performance from these dispenser modules with square holes to performance of chaff launched from the AN/ALE-29A dispenser and the Lambert LA-308A dispenser, both of which have cylindrical holes. The cartridge for the AN/ALE-29A is 1.43 inches in diameter by 5.81 inches long. The cartridge for the Lambert LA-308A dispenser is 1.568 inches in diameter by 7.625 inches long.

Experimental square and hexagonal cartridges were fabricated and functioned in the laboratory. These experimental cartridges contained the same amount (weight and volume) of chaff as the cylindrical RR-136B chaff cartridge, which is compatible with the Lambert LA-308A dispenser. In addition, special dispenser modules were fabricated to enable testing of each of the experimental square and hexagonal cartridges. Performance of the experimental cartridges launched from the dispenser modules was compared to performance of the RR-136B chaff cartridge launched from the Lambert LA-308A dispenser.

Photographic data from laboratory tests conducted by Tracor indicated a definite improvement in early chaff cloud blooming characteristics when cartridges with a square or rectilinear cross-section are used. An early chaff bloom is very desirable and would result in a major electronic warfare improvement. The Tracor team stated it could result in an increase in radar cross-section due solely to the square configuration of the chaff payload. The Tracor team reported further that a more area, volume and weight efficient system could be designed by using cartridge shapes other than cylindrical. They assigned greater packaging efficiency of square vs. round as the second reason for using square cartridges for chaff, the first being early chaff blooming.

The square cartridges launched from the experimental dispenser module during ground tests showed an average efficiency improvement in chaff blooming of 32% over the RR-136B chaff cartridge launched from the Lambert LA-308A dispenser with cylindrical holes. The square cartridges in the experimental dispenser showed average efficiency improvement in chaff blooming of 13% on a weight-volume basis as compared to the same quantity of chaff launched from an AN/ALE-29A dispenser with cylindrical holes. Based on these favorable results, it was decided to follow with a flight test in November 1971.

Of the four experimental units prepared for flight test, the standard square cartridge payload performed the best. It contained the same dipole band cuts as for the RR-136B/ALE payload, with the same theoretical radar cross-section and specification. During flight tests, the standard square cartridge payload performance was slightly superior in performance with respect to the standard RR-136B/ALE payload. This slight increase is accounted for by the square geometry of the cross-section contrasted to the circular cross section of the RR-136B/ALE, presenting corners of each band cut to airstream impact pressures for early onset of the payload ablation process, enhancing performance of all band cuts of the square cartridge configuration. The large average efficiency improvement in early chaff blooming that was observed during the ground-testing phase was not realized during the flight test phase. Nevertheless, it was concluded that a lighter and more compact pyrotechnic chaff and flare dispenser could be built which would be capable of launching chaff with a square or rectilinear cross-section. The proven benefit of this square configuration derives from the close packing of square units as compared to packing of round units. The close-packing advantage in itself is considered to be a substantial benefit. Based on the ground test and flight test data, a decision was

made to develop a dispenser with rectilinear holes and chaff cartridges in a configuration to fit the new dispenser design. The referenced experimental dispenser module in this work is the forerunner of the AN/ALE-40 chaff/flare dispenser design with rectilinear cross-section holes.

Next, the results of the exploratory development program were transferred to the Aeronautical Systems Division of WPAFB. There Mr. Eubert McDaniel and Mr. Jim Meyer of ASD started the engineering development of the AN/ALE40 in the 1970s by way of a contract with Tracor.

**Technical Directors:** Rewards for superior achievement.

During the process of discovery of data for this collection, it was noted that some individuals that had been involved in superior technological advances soon were elevated to senior positions. Perhaps this is a reward for their outstanding accomplishments. Some of the more prominent examples are:

(1) By 1951, Mr. L. T. E. Thompson was the Technical Director of NOTS. Mr. Thompson and Cdr. Chick Howard, USN first formulated the Principles of Operation at China Lake. The principles were meant to make clear that civilian scientists worked in partnership with the military at China Lake, not in subordination to it.

(2) By September 1955, Dr. William B. McLean had become the Technical Director at NOTS. Dr. McLean is the father of the Sidewinder missile.

(3) By 1960, Dr. William S. McEwan had become the Technical Director at NOTS. Dr. McEwan reported on a system for the computation of gaseous products of combustion to determine their equilibrium composition and thermodynamic properties of the combustion gases. In 1951, Dr. McEwan and Dr. Sol Skolnik developed an analog computer that electrically simulates the conditions of temperature, pressure and composition of rocket and missile combustion products.

(4) During 1982-86, Dr. Burrell Hays was Technical Director at the Naval Weapons Center, China Lake. Dr. Hays was closely associated with the re-installment of the Principles of Operation, which Rear Adm. Roland Freeman III had done away with in 1974.

(5) By 1958 Dr. Skolnik had become the Director of the Research and Development Department at the U. S. Naval Powder Factory (NPF), Indian Head Maryland. In 1951, Dr. McEwan and Dr. Sol Skolnik developed an analog computer that electrically simulates the conditions of temperature, pressure and composition of rocket and missile combustion products.

## Dates Important to the Author

The author came to the Navy during the Korean War, just out of college. He spent several years first as a military person and later as a civilian at NAD Crane developing Army, Air Force and Navy devices containing illuminating compositions. These were urgently needed in Korea. This experience later was the basis for a PhD thesis in 1973 involving illuminating compositions containing sodium nitrate. By this time Vietnam was in full swing and the Services were in dire need of protection from heat-seeking missiles. Research and development of infrared decoy flares was a natural follow-on to illumination, that being merely a change in wavelength from developing energetic materials in the visible to development of flares in the infrared. Next are some dates in which the author had some special interest.

1923: The magnesium-sodium nitrate-binder illuminating composition was invented in the Development Department, Woolwich Arsenal, UK

June 1950 - 27 July 1953: Korean War years

27 July 1953: Korean War cease-fire signed

2 August 1964: Golf of Tonkin

1965 - 1975: Vietnam War years

April 1972: Fall of Saigon

