Technical Inquiry

New Technologies in Nuclear Flash Blindness Protection

Developed by:

HDIAC
104 Union Valley Rd.
Oak Ridge, TN 37830
HDIAC Contract Number: FA8075-13-D-0001

Technical Inquiry Summary. A request was submitted to HDIAC to gather information on various new technologies for nuclear flash blindness protection. In the 1960s, the United States Air Force purchased protective eyewear and is currently looking for options for updating this technology. The customer also requests that PLZT be used as a part of the search terms.

Background Information: HDIAC processed and analyzed scientific and technical information in internal databases as well as pertinent outside sources to prepare the following summary to the inquiry.

Analysis: The initial thermal pulse for a nuclear blast can cause eye injuries in the form of flash blindness and retinal scarring. Flash blindness is caused by the initial brilliant flash of light produced by nuclear detonation. This flash swamps the retina, bleaching out the visual pigments and producing temporary blindness. During daylight hours, this temporary effect may last for about 2 minutes. At night, with the pupil dilated for dark adaptation, flash blindness will affect personnel at greater ranges and for greater lengths of time. Partial recovery can be expected in 3 to 10 minutes, though it may require 15-35 minutes for full night adaptation recovery. Retinal scarring is the permanent damage from a retinal burn, and usually only occurs when the fireball is in the field of view. PLZT or lead zirconate titanate, is an intermetallic inorganic compound and a ceramic perovskite material that show a marked piezoelectric effect, which finds practical applications in the area of electroceramics. It is a white solid that is insoluble in all solvents.

Sandia National Laboratories developed PLZT lenses for anti-flash goggles to protect aircrew from burns and blindness in case of a nuclear explosion. The PLZT lenses could turn opaque in less than 150 microseconds.

It is easy to imagine how disruptive temporary blindness would be to an aircrew operating in a complex hostile environment. Ten minutes is an extremely long time not being able to see your instruments or operate your weapons systems, and even two minutes is a long time, especially if you are in the middle of a high-speed low level penetration flight. The need for protection is therefore evident.

Figure 1. EEU-2/P goggles on an HGU-55/P helmet with PRU-36/P visor housing.

Methods of Protection

The only means of protection initially was a very dark visor combined with a monocular eye shield - an eye patch much like the ones we habitually associate with pirates and buccaneers. Later it was discovered that the protective capacity of the visor could be enhanced by applying a very thin layer of gold to the visor lens. The gold layer reduced the light transmittance of the visor to only 2% compared to approximately 15% for a standard neutral visor depending on type. The same sort of gold layer was applied also to astronauts' helmets to protect them from the damaging ultraviolet rays in the 200 to 300 millimicrons range.[1-2] Needless to say the gold-plated visor lenses were very expensive. It therefore turned out to be less practical to install them for daily use where they would be easily scratched.

The MIL-G-635 Flash Blindness Goggle Kit

An alternative to the gold-plated visor was developed in the form of a gold-plated lens for the well-known B-8 or M-1944 goggles. These could be worn when needed and otherwise tucked away in their protective box. [3,6]

The flash blindness goggle kit (MIL-G-635) consists of one container, one complete pair of goggles, one KMU-219/P modification kit (a rubber strap), and one monocular eye shield. According to PACAF regulations MIL-G-635 goggle kits are used in multiplace aircraft where they are stored on board and distributed as required, or they are used in fighter aircraft where the PLZT goggles are too large and cumbersome.[1]

It should be noted that the military specification is titled "MIL-G-635 Goggles, Sun, Wind And Dust". It does not say anything about the gold-plated visor lens. The MIL-G-635 is therefore only an identification of the frame used in the goggle kit, not a designation of the kit itself. Federal Stock Number of the goggles is 8475-00-133-3740, and the eye shield is FSN 8475-00-175-5323.[1]

The PLZT Goggles

The most advanced thermal flash protective devices in use are the PLZT goggles. These goggles are made of sandwich composite of polarized glass with an inner layer of a transparent electro-optic ceramic called PLZT.[4] When linked to an electric current, the lenses are clear. But any dangerous flash of light, such as lightning or a nuclear blast, instantaneously breaks the circuit. This causes the lenses to go black, protecting the vision of anyone wearing the helmet. The designers of the PLZT goggle had found that the material could be discharged quicker than when charged to change the transmittance. Unfortunately, in order to obtain the desired switching speed, this meant that when the nuclear flash protective goggle failed, it was basically opaque. PLZT is a ceramic material consisting of lead, lanthanum, zirconate, and titante and it can be electronically switched rapidly in polarity, such that when sandwiched with a near infrared blocking material and a fixed polarizing material, the visual transmittance can be varied from full open state (approximately 20%) to totally opaque within a ten-millionth of a second.[8]

The protection device (helmet-mounted special goggles containing four lenses) was developed under a $7.2 million contract managed by Aeronautical Systems Division at Wright-Patterson AFB, Ohio.[7] The requirements for the goggles was orchestrated by Cal Crochet, SAC Life Support System program manager, who was the direct interface with Sandia Laboratories at Kirtland AFB, NM. The idea for the goggles came from Cal's experience during his early days of flying helicopter (1957) at Eniwetok Atoll during nuclear tests under "Operation Hardtack" and later from his experiences with the flash curtain, gold goggles and eye patch problems encountered as a SAC B-47 and B-52 aircraft commander with the 306th and 509th Bomb Wings.[6]

The PLZT material was developed by two engineers, Gene Haertling and Cecil Land, from the Sandia National Laboratories in New Mexico from 1961 to 1973 (U.S. Patent No. 3,666,666, May 30, 1972, "Ferroelectric Ceramic Materials").

What initially was a visor lens for B-52 pilots was later refined into glass that fit entirely within the viewing ports of an airplane cockpit, with 6-in. diameter shutters in the viewing windows. The original PLZT goggles, military designation EEU-2/P, were developed for nuclear bombers such as the B-52 and B-1 in the Strategic Air Command (SAC), where the crewmembers would hopefully be just outside the blast, radiation, and/or heat damage radii of the weapon. A later version was designated EEU-2A/P, the difference between them being that the EEU-2A/P changes to dark faster than the EEU-2/P. By 2003 Thermal Flash Protective Devices (TFPD) were required for all PACAF aircrews on SIOP missions. Either the MIL-G-635 or PLZT goggles at the wing commanders discretion would satisfy requirements for TFPD. On aircraft that were PLZT modified, it was recommended that the PLZT goggles be used.

PLZT Goggles in Operational Use

The EEU-2/P was first put in operational use in FB-111A aircraft. The first production goggles were delivered to Chanute AFB, Ill. for the training and maintenance personnel. In early fiscal year 1980, SAC FB-111 aircraft at Pease AFB, NH and Plattsburgh AFB, NY did undergo cockpit modifications to accommodate the power pack of the thermal flash blindness protection device. The lenses are energized by low amperage 28 volt DC current.

The goggles first arrived on July 23, 1980 at Pease AFB after specified modification to the FB-111A, aircrew helmets and oxygen masks had been completed. When the goggles became operational, the 509th BMW set two firsts as alert aircrew Maj.Jack Pledger and Capt.William Rauschenbach, respectively pilot and navigator with the 393rd BS, became the world's first aircrew to be equipped with the new goggles while on alert status with FB-111A 68-0252. Soon after, the entire alert force of the 509th had achieved initial operating capabilities with the new flash blindness goggles. Each alert aircraft was fitted with two sets of goggles.

The goggles were affixed to the helmets by the individual aircrew members when their use was required. To get them in place, a crew member had 20 seconds to pick them up, raise them over head and while holding them out horizontally, slide them down the front of the helmet onto the connections and then snap the protective devises on. The PLTZ goggles were sealed in plastic inside a canvas bag that was attached with velcro under the glare shield in front of the Terrain Following Radar (TFR) scope.[4]

PLZT has its Limitations, Too

Tests in 1978 revealed that while tactical fighters could also deliver smaller nuclear weapons, use of the PLZT goggles in fighter aircraft was not favorable, due to the weight and visual transmittance. Also, the tactical fighters would probably have delivered the weapons in the daytime during this era and the effects of temporary flash blindness in the daytime would be minimal for the smaller nuclear weapons. US Army Aviation Research Laboratories (USAARL) evaluated a nuclear flash blindness protective device with the initial development of the HGU-56/P helmet program in the early 1980's. Among other things they found that the PLZT electronics, which detected a certain increase in ambient luminance in approximately 4 microseconds, could be accidentally activated by the rotor blades and when near a radar station.

However, the real problem with the nuclear flash blindness protective device requirement is the concept for helicopter operations. In the European scenario with a tactical nuclear war with the former Warsaw pact, the very basic unclassified war game models showed that the only helicopters that could survive were the ones hidden in bunkers. Therefore, it did not make sense to use a nuclear flash blindness protective device for Air Warrior or Army aviation with the known technology.

New Technologies in Industry

Although there appears to be some problems with PLZT goggles, as mentioned above, PLZT remains the leading composite of interest as a protective compound of nuclear flash blindness.

In 1981, a patent was granted to improve a controller in the electro-optic shutter of protective goggles in order to minimize light transmission to the user and maintain light transmission at the pre-flash level.[10]

In 1995, another patent was awarded for the development of a lead-containing ceramics that van be processed to high purity solutions and gels and then to powders, fibers or thin films. The development of the gel provides a relatively wide processing window, precursors of prolonged shelf life.[11]

Lastly, a patent was awarded in 1995 for nuclear flash blindness that does not employ PLZT. Photochromic Glass is known in the art world and is commonly used for the manufacture of eyeglasses which protect against sunlight. Presently, researchers are looking into its use in architecture and the automobile industry.

Photochromic glass is predominantly made from silicon dioxide, i.e. sand. A relatively large amount of boric oxide is added to the glass to make it easier to work. Next, silver and copper in the form of nitrates or chlorides are added in addition to metal halide. The mixture is heated to approximately 1,2001/2 C. causing the ingredients to melt. The mixture is then poured into a mold and it hardens into the shape of the mold.

As the glass cools, boron changes the way it fits into the base-glass structure. Consequently, the halogens that were dissolved in the glass become less soluble, come out of solution and react with the silver and copper. The reaction precipitates crystallites of silver halide that contain small amounts of copper halide. These crystallites are precipitated by reheating the mixture to approximately 6001/2 C. for 30 minutes. The crystallites are too small and too transparent to scatter or absorb visible light. Visible light occurs at the wavelength of approximately 4,000-7,000. At this point, the glass remains clear and colorless.

Crystallites are not transparent to shorter wavelengths and absorb ultraviolet (UV) light from the sun. When exposed to ultraviolet light, the silver ions, positively charged and ionically bonded to negative halogen ions, gain an electron from the copper ion to become neutral atoms. The neutral silver atoms cluster together to form tiny specks of silver metal. Many sizes and shapes of the specks are formed and thus all wavelengths are absorbed. The glass then darkens to a grey color. When illumination ceases, the copper ions regain their lost electrons. The silver metal specks reconvert to silver halide and the glass fades back to the original colorless state. Nothing is lost from the crystallites and thus the process can repeat itself without degradation.

The main disadvantage of photochromic glass for eyewear is its bulk. Thus, photochromic glass eyeglasses are normally heavy to the wearer and also thick. In addition to the bulk problem, photochromic glass is characterized by a slow response to radiation.

A 1969 publication describes a plastic photochromic panel, however, this panel has never been commercially manufactured due to its complete impracticability. The paper describing this epoxy panel, "An Eye Protective Panel for Flash-Blindness Protection Using Triplet State Photochromism", Dawson et al, Applied Optics, Vol. 8, No. 5, p.1045 (May 1969). This panel was designed for military personnel, specifically for Air Force pilots, to use as protection against radiation originating from explosions such as that caused by nuclear weapons. This panel includes two photochromic plates of epoxy plastic containing four aromatic hydrocarbon compounds which are excited to their triplet states with two xenon flashlamps. The triplet absorption of the aromatic compounds results in a photochromic absorbance of 2.42 when the panel is activated with a 3000 J flash; 85% of the final absorbance is achieved 150μ second after the beginning of the flash. The transmission of the panel recovers to 37%, five seconds after the panel darkens. The open-state transmission of the panel is 83%.

The main problem with this epoxy panel is that it must be pumped by artificial light to become photochromic. Of course, this characteristic makes this material totally unsuitable for eyeglass use. The above-described photochromic epoxy panel has not been used beyond its experimental phase. It has never been available on the market and it also has not been used by the military sector. The reason for this is self-evident; this panel is extremely impracticable due to the necessity of employing xenon lamps to excite the molecules in the epoxy. Certainly, the flash of the xenon lamps is not desirable for a pilot to have to contend with while he or she is navigating the aircraft. There is also the inconvenience of having a panel in addition to the windshield of the aircraft.

Thus, to date a photochromic plastic which is practicable and which can be commercially manufactured has not been available. The present invention provides such a novel plastic which can be used for various purposes, one of them being lightweight, inexpensive protective eyeglasses.[12]

In the 1960s, nuclear flash blindness for aviators was the biggest concern and therefore Personal Protective Equipment to shield the eyes was developed. Today, laser flash blindness is a bigger concern. A recent report issued by the FBI Cited a dramatic increase in laser strike incidents in the US. Growing from roughly 300 strikes in 2005 to nearly 4000 in 2013.[13] Lamda Guard Inc. develops state-of-the-art optically transparent thin-films using metamaterials, also known as nano-composites, that selectively block light from specific colors or wavelengths. These thin-films can be applied to virtually any glass or clear plastic surface (e.g. eyewear, protective goggles, windscreens, etc.) to block hazardous laser light aimed at aircraft cockpits, pilots, law enforcement personnel and for people who work with high intensity laser light sources.[14]

Lamda Guard's metamaterial technology can block multiple laser colors simultaneously (e.g. green and blue) and do not interfere with visibility. Its technology has higher optical transparency and can block light from wider angles. Existing laser protection solutions including safety goggles, glare shields and reflectors, are not effective because they interfere with nighttime vision as well as cockpit and runway indicators, additionally they usually do not offer protection from more than one laser color at a the same time.

Airplane manufacturers and airlines can be the first to benefit from this technology by offering flight crews full protection from the threat of laser attacks during flight. Prototypes with broadband and narrowband filtering have been successfully manufactured and tested.[14-15]

According to a June 4, 2014 press release, Airbus will be testing Lamda Guard's "metaAir" film on windscreens of its jets. This is the first time an optical metamaterial nano-composite has been applied on a large-scale surface. [16]

The metaAir film can be engineered either to absorb or reflect the desired wavelength(s). For aircraft application, the reflection approach is being used in order to block undesired light wavelengths from entering the cockpit. The reflection bandwidth is currently in the 15-20 nanometer range.

For the most common type of green laser pointer -- responsible for 93% of FAA reported incidents in 2013 -- with a wavelength of 532 nm, the film would block light from about 522 to 542 nm. Additional wavelength blocking can be added as well, such as the 445 nm blue used in powerful handheld lasers such as the Wicked Lasers S3 Arctic that has up to 2 watts (2000 milliwatts) output.

Two key advantages of blocking laser light at the windscreen are that pilots do not have to carry or use laser protective eyewear, and there is absolutely no interference with the visibility of aircraft instruments. In preliminary tests, the anti-laser film had a narrow enough bandwidth that it did not interfere with airport lights seen outside a cockpit.

Because of ultraviolet degradation to the adhesive layer that adheres the optical metamaterial to the windscreen, the film would need to be replaced after about 5,000 flight hours. This translates into overnight replacement roughly once every three years. The optical metamaterial itself would not have a flight hour restriction.

In addition to piloted commercial aircraft windscreens, Airbus will also be investigating related applications such as piloted military windscreens, UAV camera protection, and sensor protection for satellites and airborne platforms.[16]

TASC, an engineering service company that does contract work for the DoD and Homeland Defense and Security is currently conducting research on laser and broadband hazards that are expected to be a part of future combat scenarios. The work includes developing countermeasures such a as laser eye protection and the development of procedures of injury assessment. [17]

References

1. Handbook of Personal Equipment, AF Manual 64-4, 30 March 1964.
2. FM 8-10-7 Health Service Support In A Nuclear, Biological, And Chemical Environment, 22 April 1993.
3. AFI 11-301 vol.1 PACAF supplement, 18 July 2003.
4. http://www.tpub.com/content/aviation/14020/css/14020_45.htm
5. http://www.gentexoptics.com/company.htm
6. http://www.fb-111a.net/goggles.html
7. www.usaarl.army.mil/hmdbook/cp_009.htm
8. http://engineering.alfred.edu/cems/cm/material_science/mate_1.html
9. http://www.ceramicbulletin.org/months/Apr00/Haertlingfeature.pdf
10. Galbraith, Lee K. (1981). Flash Protection Controller. US Patent 4282429. August 4, 1981. http://www.google.as/patents/US4282429
11. Teowee, G. Boulton, J. M., & Uhlmann, D. R. (1995). Sol-Gel Derived Lead Oxide Containing Ceramics. US Patent 5384294. http://www.google.com/patents/US5384294
12. Lempicki, A. (1995). Doped Polysiloxane Photochromic Plastic; Radiation Protection. US Patent 5413740. http://www.google.com/patents/US5413740
13. McMahon, G. (2014). Laser Attacks Against Aircraft: A Threat to Citizens and Law Enforcement Personnel. April 2014. http://leb.fbi.gov/2014/april/laser-attacks-against-aircraft-a-threat-to-citizens-and-law-enforcement-personnel
14. Lamda Guard. http://lamdaguard.com/lamdaguard
15. Mitacs. Chemical Nanosynthesis of laser Filters for Aviation Applications. http://mitacs.ca/en/projects/chemical-nanosynthesis-laser-filters-aviation-applications
16. Anti-laser protection. 4 June 2014. http://www.laserpointersafety.com/news/news/other-news_files/category-anti-laser-protection.php
17. Thmoas, Mike W. San Antonio Buiness Journal. http://www.bizjournals.com/sanantonio/blog/2014/05/tasc-working-to-protect-aircrews-from-laser-injury.html