# Results of Investigations Conducted To Improve the Insensitive Munitions Properties of the 40mm MK281 Target Practice Cartridge

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## ABSTRACT

This paper describes the results of investigations into ways of making the 40mm MK281 Target Practice Cartridge more IM-compliant. The Marine Corps currently has an IM Waiver from the Joint Requirements Oversight Council (JROC) and will soon be returning to the JROC to provide an update on IM technology insertion efforts. The effort to date has included investigations of packaging technology for single and full packaged cartridges and an engineering study of energetics, performance, including shelf life characteristics of current M2 powder and other propellants. The results confirm that packaging options are limited by logistics constraints.

Extruded Impregnated propellant (EI-Type), manufactured by Nitrochemie Wimmis AG, was found to have far superior shelf life and aging (stability) characteristics than M2 powder. Results are presented to show that Nitrochemie Wimmis' F15080 EI powder behaves better than M2 powder in both hazard classification and slow cook-off testing.

## 1. Background

In 2003 the Marine Corps successfully fielded a new linked 40mm Target Practice (TP) cartridge for use in the MK19 Grenade Machine Gun (GMG). This cartridge, designated the MK281 Mod 0 (DODIC BA12), is based on the 40mm x 53 practice cartridge with impact signature manufactured by NICO Pyrotechnik in Germany. The DODIC BA12 cartridge is intended to replace both of the current 40mm linked TP cartridges - the M385 solid aluminum projectile variant (DODIC B576) and the M918 flash/bang variant (DODIC B584). DODIC B584 uses a fuze escapement mechanism to produce a visible flash and loud bang signature on impact. In the past, this fuze escapement has been prone to malfunctioning and produces duds. The dud rate of the B584 cartridges led to the re-procurement of B576 for training on the MK19 GMG. While B576 does not produce duds, it has a major shortcoming of not producing a visible signature on impact.

The MK281 Mod 0 TP cartridge is the result of an effort to eliminate duds on training ranges and to obtain a cartridge that produces a visible daytime signature. The MK281 Mod 0 projectile produces a visible impact signature at distances in excess of 1500 meters without the use of energetic materials and therefore does not produce hazardous duds. The cartridge case is loaded with the same M2 propellant (nominal 4.0 grams) and fitted with the same FED 215 primer as the existing TP rounds. The non-explosive marker dye powder used to produce the visible daytime signature has passed all environmental and safety tests.

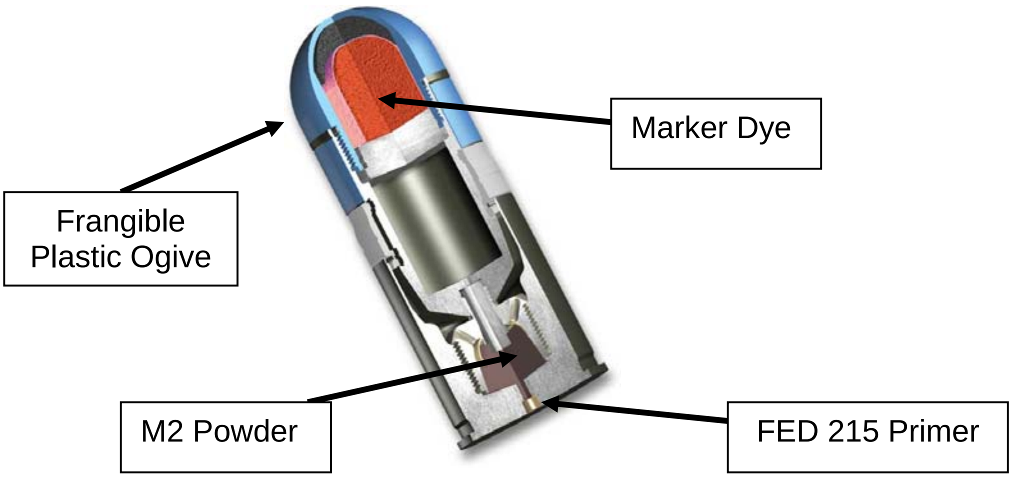


**Figure 1 – MK281 Mod 0 (DODIC BA12) Target Practice Cartridge**

The Weapon System Explosives Safety Review Board (WSESRB) provided safety approval for the production and release for Fleet use of the DODIC BA12 cartridge on 9 April 2003. However, as expected, the cartridge failed Insensitive Munitions (IM) testing with respect to slow cook-off (Type III/IV Explosion/ Deflagration response). An IM waiver request was therefore submitted through the Joint Service Insensitive Munitions Technical Panel and the CNO Insensitive Munitions Council to the Joint Requirements Oversight Council (JROC). In its letter dated 5 February 2003 approving the IM waiver request, the JROC requested that the Marine Corps investigate ways of making the round more IM compliant and to "return to the JROC providing an update on planned IM technology insertion efforts."

The work described in this paper was commissioned to provide this information by tasking NICO to investigate making the round more IM compliant. The work for the IM engineering task order was undertaken pursuant to NSWC Dahlgren Contract N00178-02-C1004 in support of PM Ammunition USMC. The contract work took place at NICO's facility at Trittau, Germany, and at Rheinmetall's Test Center at Unterlüss, Germany.

Two areas for improvement were considered:

- Improved Packaging Study
- Energetic Materials Study.

## 2. Improved Packaging Study

Figure 2 shows linked MK281 cartridges and a PA120 metal box (32 cartridges per box). Cylindrical foam inserts are placed between the cartridges with foam sheets providing additional protection.

**Figure 2 – 32 Linked MK281 Cartridges and PA120 Box**

An engineering study was conducted to investigate potential improvements to MK281 cartridges, both singly and as packaged in PA120 boxes, with respect to slow cook-off and bullet impact. Laboratory experiments were conducted with Kevlar® sheets, as used in body armor, to investigate how well this material can contain the effects (blast and fragments) of remote electrical ignition of the M2 powder from a wire passing through the cartridge ogive into the high pressure chamber in the cartridge case.

Figure 3 shows the effect of remotely igniting the M2 propellant in a single cartridge contained in a Kevlar® lined PA120 box. Sufficient heat was generated to melt part of the Kevlar®, though all the pieces did stay within the PA120 can. Whether this would have been true with the ignition of all 32 linked cartridges in a PA120 box is highly doubtful.

Other changes involving re-engineering the internal packaging material in the PA120 box were also considered. These were all ultimately rejected because of the undesirability of making any change to the feeding process in a gun already known for frequent stoppages caused by erratic feeding.

**Figure 3 - Ignited Cartridge in Kevlar® Liner in PA120 Box**

Based on these results and others using Kevlar®, it was decided not to pursue this option in testing. The high cost of Kevlar® was also a significant factor in making this decision.

The use of insulating materials in the construction of a wire-wound box containing two PA120 boxes was also considered as a means of improving IM characteristics. Materials such as pumice and chalk have proved useful in the past to prevent sympathetic detonation (fratricide) in, for example, 120mm APFSDS ammunition storage racks in tanks. Simple calculations revealed that the logistic burden caused by the weight of insulating material needed to improve the response to accidental ignition is too great to merit further consideration, particularly for systems such as these where Type I/II (Detonation/Partial Detonation) reactions do not occur in any of the five standard IM tests.

## 3. Energetic Materials Study

The Statement of Work for the IM effort required NICO to complete an engineering study comparing the energetics, performance and shelf life characteristics of current M2 propellant and other propellants. NICO was also required to provide recommendations to sustain/improve overall performance while improving IM characteristics of the MK281 cartridge.

The basis for this work was studies conducted in 1996 by the German government institute BICT. BICT (now called WIWEB) is the German national authority for the qualification of military explosives. In two separate reports [(1) (2)], BICT assessed the suitability of two candidate propellants for 40mm x 53 ammunition. These were M2 propellant manufactured by Radford Army Ammunition Plant [(1)] and Extruded Impregnated propellant (EI-Type) manufactured by Nitrochemie Wimmis AG in Switzerland [(2)]. (The EI-Type powder was called FM 1984s but, according to Nitrochemie Wimmis, is more accurately described by the specification number F15080.) M2 and F15080 are both double based propellants differing mainly in chemical composition by virtue of the small amount of stabilizers. M2 uses Centralite I (1,3-Diethyl-1,3-Diphenylurea) and F15080 uses Akardit II (1-Methyl-3,3-Diphenylurea).

The safe life, also called the chemical shelf life [(3)], covers the period of time during which the propellant can be safely stored during which there is no danger of autocatalytic decomposition of the propellant. The safe life is determined by measuring the rate of decomposition of the nitric esters or, in accordance with STANAG 4117 [(4)], by monitoring the conversion rate of the stabilizer.

The chemical stability of M2 and F15080 were compared by BICT (WIWEB) using the Bergmann-Junk Test (16 h 115°C), the Dutch Test (72 h 105°C), and the 90°C Weight Loss Test (18 days at 90°C). STANAG 4170 [(5)] stipulates the requirement to fulfill the Weight Loss Stability Test as a weight loss of ≤ 3.0% within 18 days at 90°C, without any sign of autocatalysis.

M2 propellant in BICT testing failed STANAG 4170 due to insufficient chemical stability [(1)]. This can be clearly seen in Figure 4. The weight loss after 17 days was as high as 19.7% (instead of ≤ 3.0%) with autocatalysis starting after 12 days at 90°C. M2 propellant was therefore regarded as a safety risk and is consequently banned from use in Germany.

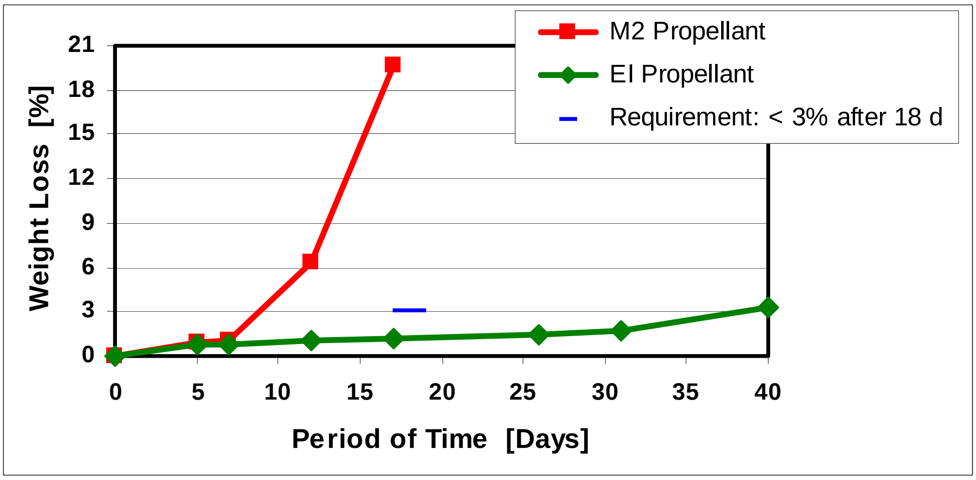


**Figure 4 - German STANAG 4170 Qualification Testing of M2 and EI Powder**

By contrast, the EI-Type propellant (F15080) was fully qualified according to STANAG 4170 [2]. All stability tests used during qualification were fulfilled. For example, the weight loss after 17 days was only 1.23% (considerably ≤ 3.0%), with autocatalysis starting only after 38 days at 90°C.

These results indicate that replacement of M2 powder by F15080 propellant in MK281 cartridges might result in a more benign response in slow cook-off testing due to the increased chemical stability of F15080 over M2.

IM testing at Crane and Dahlgren of the MK 281 Mod 0 cartridge, as part of type classification testing, showed that slow cook-off generated the most severe response of the standard IM tests. This is perhaps not surprising insofar as NICO's propulsion system design, in which the cartridge case is screwed to the projectile, prevents the propellant gases from causing shot start until sufficient pressure has been reached to fracture the metal at the pre-determined breaking point.

## 4. Test Results

The following test schedule was adopted on the baseline configuration cartridges (MK281 Mod 0 cartridges containing M2 powder).

| | |
|---|---|
| Initial Inspection | Visual inspection |
| Weighing (cartridges 1-64) | Gauging (cartridges 1-64) |
| Baseline Functioning Tests (3 x 13) | Hot and cold conditioning |

Functioning
Temperature Shock Test to MIL-STD-810F (unlinked cartridges 1-64), 71°C for 4 hours, -51°C for 4 hours, 3 cycles in 24 hours
Visual inspection
Link cartridges
Pack into PA120 boxes (boxes 1 and 2)
Secured Cargo Vibration Test to ITOP 1-2-601(boxes 1 and 2)
Visual inspection
Sealing Test (cartridges 1-64, unlinked)
Hot/Cold Functioning tests
Cold functioning (box 1)
Hot functioning (box 2)
Bullet Impact Test to MIL-STD-2105 (boxes 3 and 4)
Slow Cook-Off Test to MIL-STD-2105 (box 5)
1.5 meter Bare Drop Testing to ITOP 4-2-602 (cartridges 129-138)
-51°C (cartridges129-133)
63°C (cartridges 134-138)
Proof functioning at -20°C (cartridges 129-133)
Proof functioning at 50°C (cartridges 134-138)
Hazard Classification Testing to TB 700-2 (boxes 6, 7 and 8).

The cartridges for secured vibration testing had previously been subjected to temperature shock. They were then linked and loaded into two PA120 boxes. The PA120 box with 32 linked cartridges was subjected to ITOP 1-2-601 testing along its longitudinal and transverse axis.

The cartridges passed visual inspection after vibration testing and were then functioned cold (box 1) and hot (box 2). The cartridges all satisfied the firing, functioning and casualty test (ITOP 3-2-045).

The ITOP 4-2-602 bare cartridge drop testing was carried out for five cartridges at the lower storage temperature (-51$^{o}$C) and then fired at -20$^{o}$C. A further five cartridges were subjected to the drop test at the upper storage temperature (71$^{o}$C) and then fired at 50$^{o}$C. All ten cartridges passed firing, functioning and casualty testing.

MIL-STD 2105 bullet impact testing was carried out on two PA120 boxes with a 3-round burst fired lengthwise along one box and widthwise along the other. In neither case did a reaction occur greater than burning (Type V reaction). The PA120 boxes distorted but easily contained the fragments.

The PA120 box with its lid removed after lengthwise bullet impact is shown in Figure 5. One bullet clearly penetrated a 40mm cartridge case, shown outside the PA120 box, and ignited the propellant.

**Figure 5 - Lengthwise Bullet Impact on PA120 Box**

It was concluded that the cartridge design using M2 powder meets the bullet impact requirements, with a reaction no greater than burning (Type V).

MIL-STD 2105 slow cook-off testing was carried out on a PA120 box containing 32 linked MK281 Mod 0 cartridges. Four thermocouples were placed at various locations throughout the insulation surrounding the PA120 can and within the outer heated aluminum box. One thermocouple (designated number 5 in Figure 6) was placed through a small hole inside the PA120 box. This thermocouple is closest to the energetic materials in the cartridge case and therefore more accurately represents the actual temperature at which an exothermic reaction occurs. Thermocouples 1 to 4 register higher temperatures than thermocouple 5 at any given time because they are closer to the external source of the heat (an external fan heater).

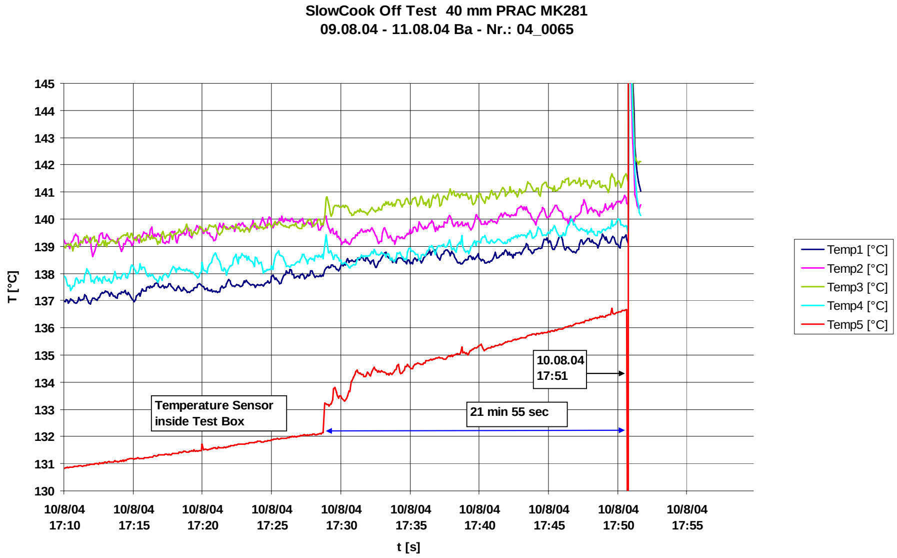


**Figure 6 - Temperature /Time Profiles in Slow Cook-Off Testing of MK281 Cartridges using M2 Propellant**

An exothermic reaction is clearly seen to occur around 132°C, probably caused by the ignition of just one cartridge. The temperature then continues to rise on a parallel path to the original temperature/time curve in Figure 6 until a massive exotherm occurs at about 136°C (277°F). This exotherm is obviously associated with the ignition of many cartridges. The physical disruption occurring at this temperature effectively ended the experiment.

The force of the pressure release in the PA120 box around 136°C was sufficient to cause many of the cartridges to rupture at the pre-determined break point connecting the projectile to the cartridge case. In one case this force was sufficient to cause the projectile to travel through the hole in the distorted PA120 box and through the outer aluminum box.

Unfortunately the experimental setup for slow cook-off testing in this work differed slightly from that in the original Crane testing of the MK281. It is therefore not possible to make any direct comparison between the results then and now. Even so, it is clear that the MK281 cartridge loaded with M2 propellant continues to fail slow cook-off testing (Type III or IV response).

The results of the energetic materials study (section 3) show that Nitrochemie Wimmis' F15080 EI powder has far superior thermal aging characteristics than M2 powder. The slow cook-off test was repeated at Rheinmetall's Unterlüss test site using a PA120 box of 32 linked MK281 Mod 0 cartridges, but this time loaded with Nitrochemie Wimmis F15080 powder instead of M2.

Figure 7 shows the temperature/time profiles in repeated slow cook-off testing using exactly the same experimental set-up and cartridges as previously, but this time using the nominal same mass (4.0 grams) of F15080 powder as M2 powder.

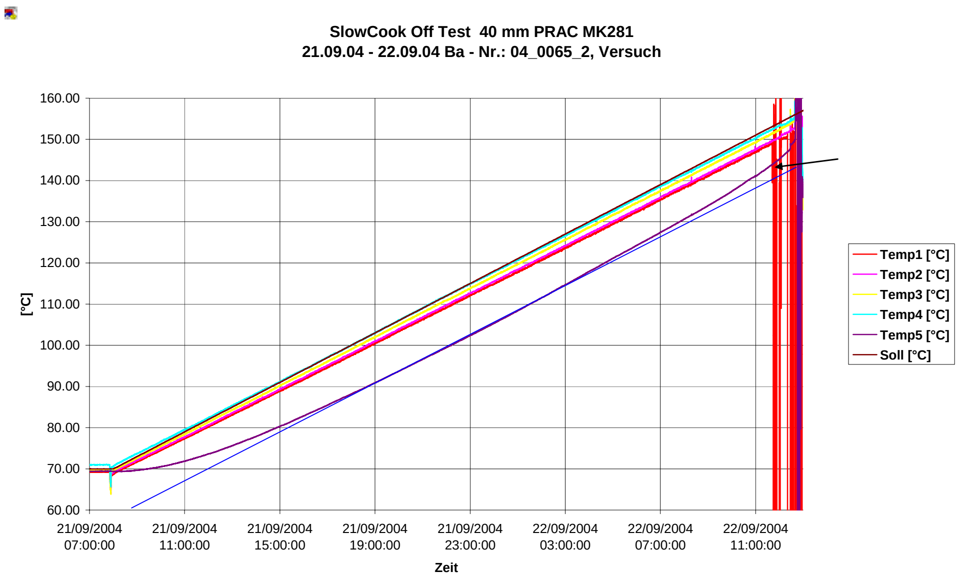


**Figure 7 – Temperature/Time Profiles in Slow Cook-Off Testing of MK281 Cartridges using F15080 Propellant**

In Figure 7, thermocouple 5 measuring temperature 5, is the one placed within the PA120 box closest to the cartridges. It is clear from Figure 7 that physical disruption of the cartridges caused by a massive exotherm occurs around 143$^{o}$C (289$^{o}$F). This temperature is around 7 degrees Centigrade higher than the equivalent temperature for M2 powder. More significantly, there is no evidence from Figure 7 of an exotherm as large as that occurring around 132$^{o}$C using M2 propellant.

The maximum event using F15080 propellant in the MK281 cartridge is now a Type IV (Deflagration) or V (Burning) reaction. None of the cartridges or their component parts was forcibly ejected from the PA120 box.

Based on these test results, Nitrochemie Wimmis' F15080 has now replaced M2 powder in all cartridges containing NICO's high velocity 40mm propulsion system. These include:

- 40mm MK 281 Mod 0 (DODIC BA12) TP (Day Signature) Cartridge
- 40mm MK 281 Mod 1 (DODIC BA21) TP (Day and Night Signature) Cartridge
- 40mm MK 285 Mod 0 Air Bursting (PPHE/SD) Cartridge.

## 5. Conclusions

5.1 A Kevlar® wrap around the cartridges in a PA120 box will possibly improve some system IM characteristics but is probably not worth the additional cost.

5.2 The addition of shock attenuating materials to the external packaging of two wire-wound PA120 boxes will also improve the IM characteristics but poses a prohibitively high additional weight burden.

5.3 M2 powder has far inferior stability characteristics than Nitrochemie Wimmis' Extruded Impregnated (F15080) powder.

5.4 Nitrochemie Wimmis' F15080 powder behaves better than M2 powder in both hazard classification and IM testing.

## 6. Future Work

Further studies are being undertaken to allow the MK281 cartridge case to vent at temperatures below the auto-ignition temperature of the powder and primer. The aim of these studies is to demonstrate a Type V (Burning) IM response in all conditions of adverse thermal impact (slow and fast cook-off).

More recently, Nitrochemie Wimmis has widened its EI-family of propellants to include EI+ and EI++ types [6]. These will also be investigated for their ability to impart improved thermal and mechanical IM characteristics to high velocity 40mm ammunition.

## 7. References


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