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EFFECT OF 2.45GHz MICROWAVE RADIATION ON DIVERSE EXPLOSIVES

by

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ABSTRACT

A preliminary study of the effect of 2.45 GHz microwave radiation on a variety of explosives was performed. A small sample, around 20 to 35 grams, of explosive was placed in a Pyrex beaker and then irradiated in a small domestic microwave oven. The explosives studied were Composition B, an aluminized RDX/TNT mixture, a plastic bonded explosive (PBX) based on RDX and an energetic GAP binder, a PBX based upon NTO/HMX and a GAP binder, and a PBX based upon RDX and HTPB binder (DREV's CX-84A). In all cases, only a burning reaction was observed. This memorandum shows that the time to reaction and rate of burning varied from explosive to explosive.

RÉSUMÉ

Une étude préliminaire de l'effet d'irradiation à 2,45 GHz sur divers explosifs a eté éffectuée. Un petit échantillon (environ 20 à 35 grammes) de chaque explosif a été mis dans un bécher en Pyrex et irradié dans un petit four à micro-ondes domestique. Les explosifs étudiés étaient la Composition B, un mélange aluminisé de RDX et TNT, deux explosifs composites à liants énergétiques à base de PAG: l'un avec l'hexogène et l'autre avec l'ONTA et l'octogène, et un explosif composite à base de RDX et de HTPB (CX-84A du CRDV). Dans tous les cas, seulement une combustion a été observée. Ce mémorandum montre que le temps de réaction et la vitesse de combustion varient d'un explosif à l'autre.

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FIGURE 1

EXECUTIVE SUMMARY

The Canadian Forces use microwaves in radar systems, radio communications, missile guidance systems and even to reheat food. Accidental or deliberate exposure of explosives to microwave radiation is inevitable given the ubiquity of sources. Surprisingly, the open literature is quiet on the effects of microwaves on explosives. This work is a preliminary investigation to see if there could be potential safety problems.

In the present preliminary study, small samples (20-35 g) of various common and experimental explosives were placed in a typical domestic microwave oven and then heated. In all cases, reactions no more violent than burning were seen. These results should not be extrapolated to much larger samples. However, they are encouraging for the safety aspects as well as for the application of this technology to the destruction of explosives.

Consequently, the implications of this work for the CF could be significant. If a detonation occurs in a larger sample, many practical applications can be envisaged. In fact, recent work in Australia suggests that *in situ* destruction of plastic landmines by microwaves is possible. Through the auspices of TTCP, a collaborative program could be set up in this field.

LIST OF SYMBOLS

A	area of sample
c	speed of light
C_p	specific heat capacity
I_o	incident intensity
l	length of sample
t	time
T	temperature
ϵ', ϵ''	real and imaginary parts of dielectric constant
κ	absorption constant
ν	frequency
ρ	density

1.0 INTRODUCTION

In the last several decades, microwaves have become ubiquitous in military and civilian electronics. Given this, exposure of explosives to microwaves, whether accidentally or deliberately, seems bound to occur. It seemed evident that this occurrence should be checked under controlled conditions to see if this would be hazardous or not. This preliminary document presents the results of tests in which explosives were purposely heated in a typical domestic microwave oven.

This work was carried out at DREV between April and June 1996 under Thrust 2E, Munitions and Delivery Systems.

2.0 EXPERIMENTAL DETAILS

The experiments were all performed using identical domestic microwave ovens, a DANBY model 665/2. This oven has a nominal power rating of 700 W and a capacity of 1.0 ft^3. The operating frequency of the microwave radiation is 2.45 GHz. The heating effect of an oven was verified using a beaker of water (see Fig. 1) which shows a linear relationship between sample temperature and time. Of course, other materials should show a linear relationship but not at the same rate. For most of the tests, the front grill was removed to allow better viewing of the samples. A sample at room temperature (about 20°C) was placed in a standard laboratory Pyrex beaker (250 ml size) and the beaker was

affixed on a 1" thick block of plastic using glazier's putty. The block-beaker combination was then positioned on the center of the oven on a rotating plate, affixed to the plate again using glazier's putty. The glazier's putty has two advantages: it is very sticky and more importantly does not lose its effectiveness at the highest temperatures encountered during these tests. The oven was used on its highest power setting. The delayed start feature of the oven was used for safety purposes, i.e. no personnel were present in the firing bay when the oven started. The heating process and subsequent reactions were recorded using a video camera.

3.0 RESULTS AND DISCUSSION

In all cases, only burning reactions were observed. The time to ignition, the speed of burning and other details of the reaction did vary from explosive to explosive. These are summarized for each explosive in this section.

3.1 Composition B

Sample 1 was a right cylinder 25 mm in diameter and 42 mm high (35 g). Sample 2 was a right cylinder 25 mm in diameter and 28 mm high (25.1 g). It required about 6 min of heating for sample 1 and 14 min for sample 2 before flames were observed. They burned with a steady flame for about 45 s and then no further activity occurred.

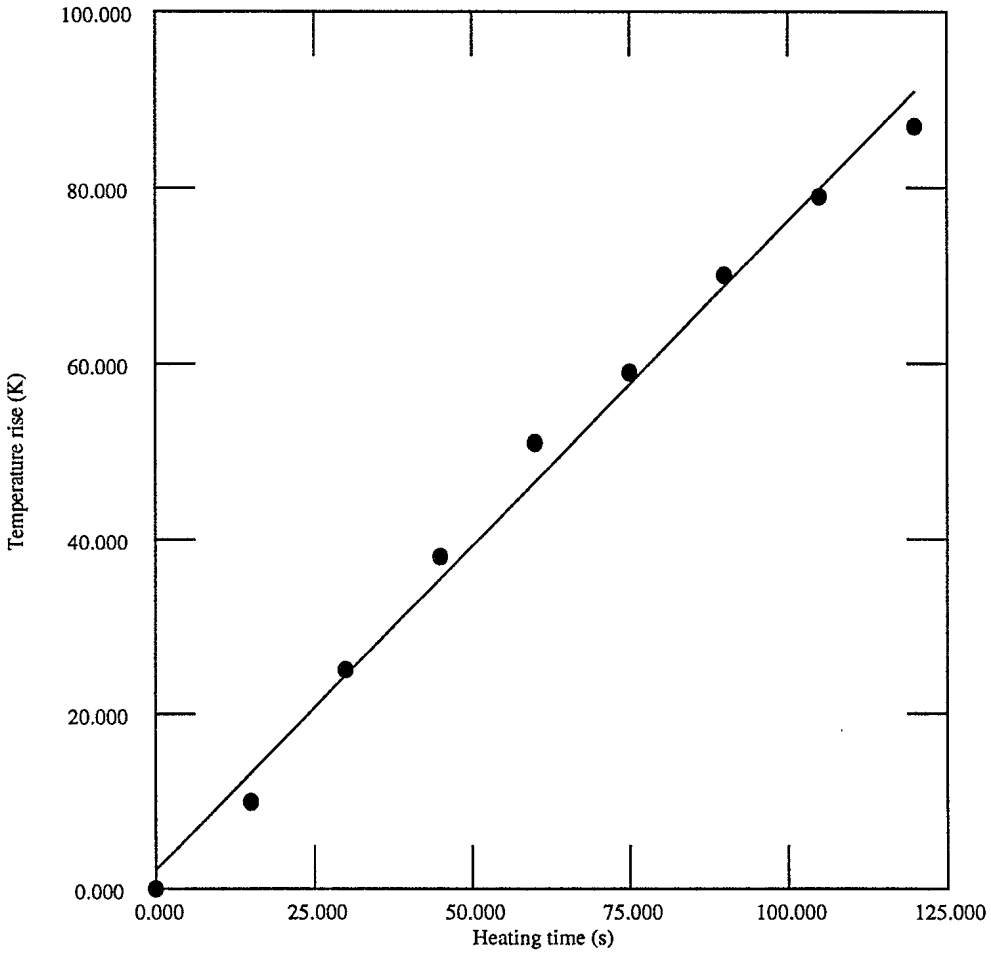

FIGURE 1 – Heating of 150 ml of water in a Danby 665/2 microwave oven

Unfortunately, these were the only tests for which the front grill was not removed, making the clear viewing of the sample impossible. A test was tried with the grill removed but a power interruption occurred after 15 minutes. In this test, no visible effect (melting or otherwise) happened. However, after a 30 min wait (for safety reasons), we found that the sample was warm but had retained its cylindrical shape.

3.2 CHE-291

CHE-291 is a DREV-developed plastic bonded explosive (PBX) made of 85% HMX and 15% GAP-based energetic binder. Both samples were right cylinders 25 mm in diameter and 25 mm high (21.7 g). Sample 1 started to burn at 1:01 min, sample 2 at 1:23 min. Both seemed to melt a bit a few seconds before ignition. They burned brightly for about 40 s with a few flashes thereafter.

3.3 CSM95-20

CSM95-20 is a DREV-cast 40% RDX/35% TNT/25% Al mixture similar to many underwater explosives used in sea mines and torpedo warheads. Both samples were 32 mm in diameter and 25 mm high (36.1 g and 35.2 g). Sample 1 melted after about 2:13 min of heating and started burning 1:13 min later. Sample 2 melted after 1:58 min of heating and started burning 1:19 min later. They burned vigourously for 30-40 s with no subsequent activity.

3.4 CHN-037

CHN-037 is a DREV-developed PBX based upon a 76% NTO/HMX mixture and a 24% GAP-based binder. Both samples were right cylinders 25 mm in diameter and 25 mm high (21.8 g). Sample 1 started to burn after 1:01 min and sample 2 after 0:56 min of heating. Both seem to generate a combustible gas which burns first, then the solid part starts to burn. They burned quietly for 45-60 s and then bright, irregular flashes continued for several minutes (perhaps due to arcing in the carbon soot).

3.5 CH-1240

CH-1240 is the DREV PBX CX-84A, a mixture of 84% RDX and 16% HTPB binder. Both samples were one half of a "dogbone" used for mechanical properties tests at DREV and were roughly 60 mm long, 12-25 mm wide and 12 mm thick (19.8 g and 20.1 g). For sample 1, a whitish-yellow gas was generated after 6:06 min of heating with flames starting at 6:24 min. For sample 2, the gas was generated after 6:04 min and flames appeared at 6:23 min. Both burned quietly for about 35 s and then no further activity.

3.6 Discussion

According to Murray (Ref. 1), there should have been no reaction for these explosives. However, his experimental conditions were much different. In particular, he exposed

his samples to a series of short (6.5 μs), high intensity (1130 W cm^{-2}) 2.88 GHz microwave pulses for 50 s at a pulse rate of 50 Hz. This present set of experiments used lower intensity, continuous irradiation for several minutes of exposure time. The longer exposure time will heat the sample quite a bit.

The heating effect of microwave radiation can be estimated. Consider a uniform slab of material upon which a plane microwave impinges. The intensity is reduced exponentially by the material as the wave traverses the slab. The difference between the incident and transmitted intensities is due to absorption by the material and is responsible for its heating. In energy terms, this is expressed by:

$$I_o(1 - \mathrm{e}^{-\kappa l})A\Delta t = C_p \rho A l \Delta T$$

where I_o is the incident intensity. A material's properties are specified by its absorption coefficient κ, its density ρ and its specific heat C_p. A sample's geometry is specified by its thickness l and its area A. (The area is here for clarity but is not needed as it cancels out in the equation.) An exposure time Δt gives rise to a temperature rise ΔT. If the temperature increase in a characterized sample is known as a function of time, I_o can be found by simple rearrangement of the above equation. To a good approximation, I_o is a characteristic of a given microwave oven. Once I_o and a second material's properties (C_p, etc.) are known, the heating rate for a new sample can be calculated and hence the temperature can be found by another rearrangement of the fundamental equation.

The considerations of the preceding paragraph will now be applied to the present

experiments. The information given in Fig. 1 and the literature value for the absorption of 2.45 GHz microwave radiation by water, about 0.8 cm^{-1} (Ref. 3, p.291), are sufficient to deduce the intensity (I_o) in the microwave ovens. The typical length l is simply estimated by the cube root of the volume of the water sample used. The heat capacity of water is 1 cal g^{-1} K^{-1} and its density is just 1 g cm^{-3}. With these numbers, the estimated I_o is 163000 W m^{-2}. With this and the literature values for Composition B according to Murray (Ref.2, p.17), the heating rate and temperature in the Composition B sample will be estimated. The absorption coefficient of 2.5 GHz radiation in Composition B is around 2 cm^{-1} (upper limit), its density 1.7 g cm^{-3} and its heat capacity 0.234 cal g^{-1} K^{-1}. A 20 g sample has a volume of 11.8 cm^3 and a typical length of 2.27 cm. For example, using only five minutes of heating, we should see a temperature rise of 1282 K. If this were indeed the absorption coefficient, reactions should have occurred much sooner than experimentally observed times of between 6 and 14 minutes of heating. Thus, the true absorption coefficient is probably much lower.

A few other measurements of the absorption coefficient for Composition B can be found in the literature (Refs. 4,5). These are generally disguised as the frequency (ν) dependent complex dielectric constant. If the real part of the dielectric constant (ϵ') is much greater than the imaginary part (ϵ''), the absorption coefficient is given by:

$$\kappa = [\frac{\epsilon''}{\epsilon'}][\frac{2\pi\nu\sqrt{\epsilon'}}{c}]$$

where c is the speed of light. In Ref. 4, the values are $\epsilon' = 2.4$ and ϵ'' between 0.005 and

0.04, for a κ between 0.0017 cm^{-1} and 0.013 cm^{-1}. In Ref. 5, different values are given: ϵ' = 2.3 and ϵ'' = 0.00112, for a κ of 0.00038 cm^{-1}. The values from Ref. 5 are calculated by using the weight fraction averages of their RDX and TNT values. At κ=0.1 cm^{-1}, the temperature rise would be 258 K, at κ=0.01 cm^{-1}, 29 K and at κ=0.001 cm^{-1}, 2.9 K. Since reactions were observed experimentally, the temperatures must have been well above ambient conditions and thus, a significant amount of absorption must have occurred. With the value of κ deduced from Ref. 5, only a minor temperature rise (a few degrees) should occur and hence, this κ is certainly underestimated. Using the largest κ deduced from Ref. 4, a temperature rise of several tens of degrees should occur. This κ seems to be low also but does give a more reasonable temperature rise and hence is probably closer to the true value.

Unfortunately, it is impossible to state at what temperature the reactions occurred for most of the explosives as thermocouples could not be used (they short out when placed in the oven). However, an estimate can be made for CSM as melting was observed for this explosive. Since its melting point (about 80°C) and the time to melting (about 2:00 min from 20°C) are known, the heating rate is found (30 K min^{-1}) and therefore, the temperature at ignition can be found by linear extrapolation (neglecting any temperature dependent thermal properties and latent heat effects upon melting) for 3:21 min of heating; it is 121°C. This is well below the usual reaction temperature for a typical RDX/TNT/Al mixture (around 230°C for the explosive H-6 in a differential thermal analysis test). It is not clear from the present tests whether the estimated temperature is low or another

phenomenon is at work in the presence of microwave radiation. For example, the absorption coefficient may be different after melting. More experimental work would be needed to determine the true temperature at ignition.

One hypothesis can be made to explain the general trends: the explosive components of the various samples are insensitive to microwave radiation and any absorption is due to the other ingredients. For instance, Composition B is approximately 99% RDX and TNT explosive crystals and only 1% inert wax. Thus, it should be insensitive to radiation. The other RDX/TNT explosive studied, CSM95-20, has a large aluminum component which should absorb well microwaves, suggesting that this explosive should react more quickly, as indeed it did.

On the other hand, a GAP-based binder absorbs well the microwaves. This is the reason why CHE-291 and CHN-037 react quickly. CH-1240 has an HTPB binder which does not absorb microwaves efficiently and thus it takes longer to react. This hypothesis could be checked by measuring the absorption of microwaves by pure samples of the explosive materials and other ingredients used to make the explosives. The absorption should increase for HTPB binder, Al powder and GAP binder. The explosive materials should show relatively small absorption. In Ref. 4, this is the general trend that they observed.

Sample size effects should be investigated in further work. If a detonation occurs in a larger sample, the implications will be important. For example, *in situ* destruction of plastic landmines would be possible. This was recently reported in Australia (Ref. 4). The

safety aspects of explosives in close proximity to microwave sources (e.g. radars) would also have to be reevaluated.

4.0 CONCLUSIONS

Microwave radiation at 2.45 GHz does have an effect on a wide variety of explosives including Composition B. For small samples (under 40 g), there is a definite fire hazard after a few minutes of continuous exposure. There does not seems to be a danger of violent reaction but this conclusion should not be extrapolated to larger samples. Further studies, especially for landmine destruction, are recommended. These could include size effects and frequency dependence effects.

5.0 ACKNOWLEDGMENTS

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