# EVALUATION OF AIR-DEPLOYABLE INCENDIARY DEVICES FOR THE IGNITION OF OIL ON WATER

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## ABSTRACT

This report summarizes the results of field experiments conducted in Waterloo, Ontario between September 29, 1977 and January 31, 1978. Several different igniter designs were evaluated for their ability to ignite confined slicks of Norman Wells (N.W.) crude oil. Ignition probabilities were determined for each igniter design, based upon their performance in the static and air deployment tests.

During the static test runs, the ignition and burning of oil slicks were correlated with variations in oil thickness, oil "age", and wind conditions. Oil and water temperatures as well as regression burning rates were determined for burning slicks.

During the air deployment test runs, the igniters were deployed onto oil slicks from a tower 11.5 m in height. To make them adaptable for air deployment, starters and delay mechanisms were devised for igniters. Flame radiation intensities and free fall velocities were determined for the igniteres used.

The thickness of residues ranged between 0.55 mm and 1.17 mm. Fresh N.W. crude was easier to ignite on water than aged N.W. crude. Thicker oil slicks were found to burn (or regress) at a greater rate than thinner slicks. During combustion the oil attained a maximum temperature of approximately 250°C.

Solid fuel and solid propellant igniters equipped with safety fuses were found to be the most reliable igniters for air deployment, Kontax and solid propellant igniters emitted more intense flame radiation than solid fuel igniters, but did so for a shorter duration than solid fuel igniters.

Environment Canada. Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 1st. Proceedings. March 15-17, 1978, Edmonton, Alberta, Canada, Environment Canada, Ottawa, Ontario, 148-163 pp, 1978.

## 1.0 INTRODUCTION

If crude oil (from a well blowout, for example) was trapped under first year sea ice, it is possible for it to rise to the ice surface through brine channels created during the spring thaw (Norcor, 1975). Crude oil on the ice surface would adsorb solar radiation, thus generating heat that would accelerate the oil rise, and melt the ice itself. In this fashion, confined pools of oil on water would be formed.

Provided the thicknesses of the slicks formed were equal to or greater than the minimum ignitable thickness of the oil (Energetex Engineering, 1977), direct burning of these slicks by means of air-deployable igniters is feasible.

## 2.0 IGNITER REQUIREMENTS AND SELECTION

In order to successfully burn oil slicks, an igniter must supply sufficient energy to initiate and maintain three physical processes:

(1) Local heating and volatization of oil near the igniter

(2) Local ignition of oil vapours near the igniter

(3) Flame spread from the local ignition point of oil to the entire slick surface.

The igniters must be of a "soft" type (i.e. produce no significant disturbance of the slick). Igniters must also be equipped with starters (or delay mechanisms) for activation after landing, otherwise the igniter flames would be extinguished (by temporary submergence in water) upon landing.

Such igniter and starter combinations must be reasonably safe to handle and deploy, and the fuel of the igniters must be non-toxic to marine organisms. Since these devices must be available and functional upon demand, they should be easy to store and transport, functional in a variety of weather and slick conditions, and economical to manufacture.

In accordance to the requirements previously stated, five igniter types were selected for testing:

(1) Gasoline plus sodium

(2) Solid propellant (ammonium perchlorate oxidizer plus polyurethane binder)

(3) Solid fuel (gelled kerosene)

(4) Kontax (sodium plus calcium carbide)

(5) Kontax plus gasoline.

Kontax igniters were designed mainly for the purpose of oil slick combustion and had been previously used in air deployment applications (Anonymous, 1969). Solid propellant igniters had the advantage of providing a strong flame, which would not be extinguished under windy conditions. Solid fuel igniters were selected because solid fuel was not rapidly consumed by flames and was also very inexpensive. The sodium and gasoline igniters were chosen, since they would be very inexpensive to manufacture.

## 3.0 STATIC BURNING TEST

### 3.1 Test Objectives

The objectives of the static test were:

(A) To evaluate five igniter designs selected for ignition of continued slicks of N.W. crude oil;

(b) To determine how regression burning rates and combustion behaviour were affected by variations in oil thickness, oil "age", and wind conditions;

(c) To monitor oil and water layer temperatures during the burning of slicks.

### 3.2 Experimental Setup

The burning area was restricted to 1 square meter. For each of the igniter designs tested, the following parameters were varied:

(1) Oil slick thickness (3 mm or 10 mm)

(2) Oil type (fresh or "aged" Norman Wells crude oil)

(3) Wind conditions (windy or calm).

The crude oil was aged by exposing it to Southern Ontario winter conditions for a period of two weeks. The temperatures of the oil and water layers during oil slick combustion were monitored by copper-constantan thermocouples, connected to chart records. The preheating, ignition, and burning times were recorded for most of the runs.

Flash and fire point determinations (ASTM, 1972) were carried out upon fresh, aged, and residual samples of N.W. crude oil.

## 3.3 Results and Conclusions

For all runs performed the residue thicknesses ranged between 0.55 mm and 1.17 mm. For burns performed under windy conditions, the remaining residue was slightly increased.

The preheating time was essentially zero for fresh N.W. crude oil since the temperature from the activated igniters was much greater than the flash point of fresh N.W. crude. The preheating time for aged slicks ranged between 25 seconds and 4 minutes, and was dependent upon wind conditions and the igniter used. Under calm weather conditions, the ignition time for the slicks was less than under windy conditions.

Regression burning rates for slicks 3 mm in thickness (approximately 1.5 mm/min.) are considerably less than the regression burning rates for oil slicks 10 mm in thickness (approximately 2.5 mm/min.). The averaged regression burning rates are shown in Table 1. In general, these rates are not linearly dependent upon the thickness of the oil slick. Regression burning rates are lower for thinner slicks (due to the increased cooling effect of water) and are slightly increased under windy conditions (since more oxygen is supplied to intensify combustion).

Flash and fire points of residue from the burning of slicks 10 mm in thickness are higher (by approximately 27$^{o}$C) than the flash and fire points of residue from the burning of slicks 3 mm in thickness (see Table 2). During the burning of thicker oil slicks, more time was allowed for the oil to burn, thus allowing a larger percentage of combustible components to burn away before the flames were thermally quenched.

During the slick burning process, the oil layer attained a maximum temperature of 250$^{o}$C and the uppermost 5 mm of the water layer attained a maximum temperature of 50$^{o}$C (see Figure 1). The temperature difference between maximum oil and water layer temperatures indicates the creation of a large temperature gradient in the water, thus revealing a large degree of heat transfer from the flames to the water.

Solid fuel, solid propellant, and Kontax igniters were effective in oil slick ignition (see Table 3), having ignition probabilities of 84%, 89%, and 100%, respectively. Sodium and gasoline igniters were ineffective here, due mainly to problems encountered with the sodium starter.

TABLE 1

AVERAGE REGRESSION BURNING RATES OBTAINED FROM STATIC TEST

| Oil Layer Height (mm) | Type of N.W. Crude Burned | Weather Conditions | Average Regression Burning Rate (mm/min) |
|---|---|---|---|
| 3 | Fresh | Windy | 1.542 |
| 3 | Fresh | Calm | 1.480 |
| 3 | Aged | Windy | 1.775 |
| 3 | Aged | Calm | 1.348 |
| 10 | Fresh | Windy | 2.190 |
| 10 | Fresh | Calm | 2.184 |
| 10 | Aged | Windy | 2.850 |
| 10 | Aged | Calm | 2.409 |

TABLE 2

AVERAGE FLASH AND FIRE POINT VALUES OBTAINED FROM STATIC TEST*

| Slick Height (mm) | Crude Oil Type | Average Flash Point of Residue (°C) | Average Fire Point of Residue (°C) |
|---|---|---|---|
| 3 | Fresh | 166 | 171 |
| 3 | Aged | 155 | 161 |
| 3 | Aged & Fresh | 161 | 166 |
| 10 | Fresh | 193 | 204 |
| 10 | Aged | 183 | 187 |
| 10 | Aged & Fresh | 189 | 197 |

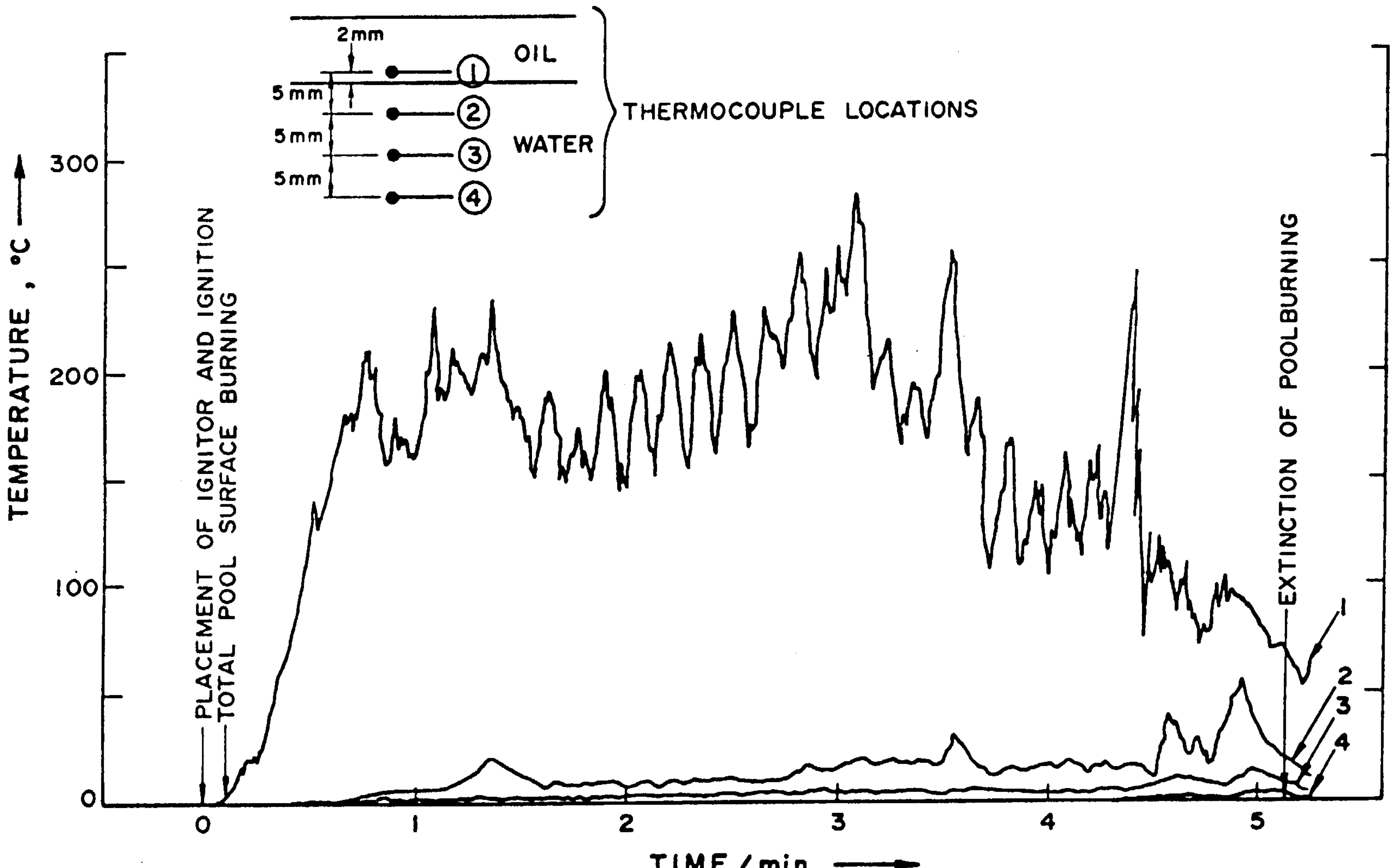


FIGURE 1
**TEMPERATURE PROFILE OF BURNING CRUDE OIL SLICK AND WATER SUBSTRATE (FRESH NORMAN WELLS, 10mm. thickness)**

TABLE 3

IGNITION PROBABILITIES FROM STATIC BURNING TEST*

| Igniter Type | Number of Successful Runs | Number of Failures | Total Number of Runs | Ignition Probability (Percent) |
|---|---|---|---|---|
| Kontax | 6 | 0 | 6 | 100 |
| Solid Fuel | 21 | 4 | 25 | 84.0 |
| Solid Propellant | 16 | 2 | 18 | 88.9 |
| Sodium & Gasoline | 0 | 3 | 3 | 0 |

## 4.0 STARTERS

Three mechanisms were considered for the delayed activation of air-deployed igniters:

(1) Chemical starters

(2) Electrical starters

(3) Fuse wire.

The three mechanisms above were used to activate solid propellant igniters, whereas only chemical starters and fuse wire were used to activate solid fuel igniters.

## 5.0 AIR DEPLOYMENT TEST

### 5.1 Test Objectives

The objectives of the air deployment test were:

(1) to evalute each starter and igniter combination for their ability to ignite a confined slick of N.W. crude oil when air deployed

(2) to measure the intensity and duration of flame radiation from the igniters.

### 5.2 Experimental Setup

To simulate deployment from low-flying aircraft, igniter and starter combinations were dropped from an aluminum tower (11.5 m high) onto two landing sites:

(1) oil floating on water, 5 cm above solid ice

(2) oil floating on a body of water, 1 m in depth.

Slicks consisted of both fresh and aged N.W. crude oil, and ranged between 2.9 mm and 6 mm in thickness.

From motion pictures taken of the igniters' free fall, the impact velocities of the igniters (the velocities of igniters upon contact with the oil surface) were determined (see Figure 2).

The intensity and duration of flame radiation from solid fuel, solid propellant, and Kontax igniters were measured by means of a Total Radiation meter equipped with a chart recorder (see Figure 3).

The following devices were evaluated:

(i) Kontax igniters (chemical starter self-contained) with and without gasoline.

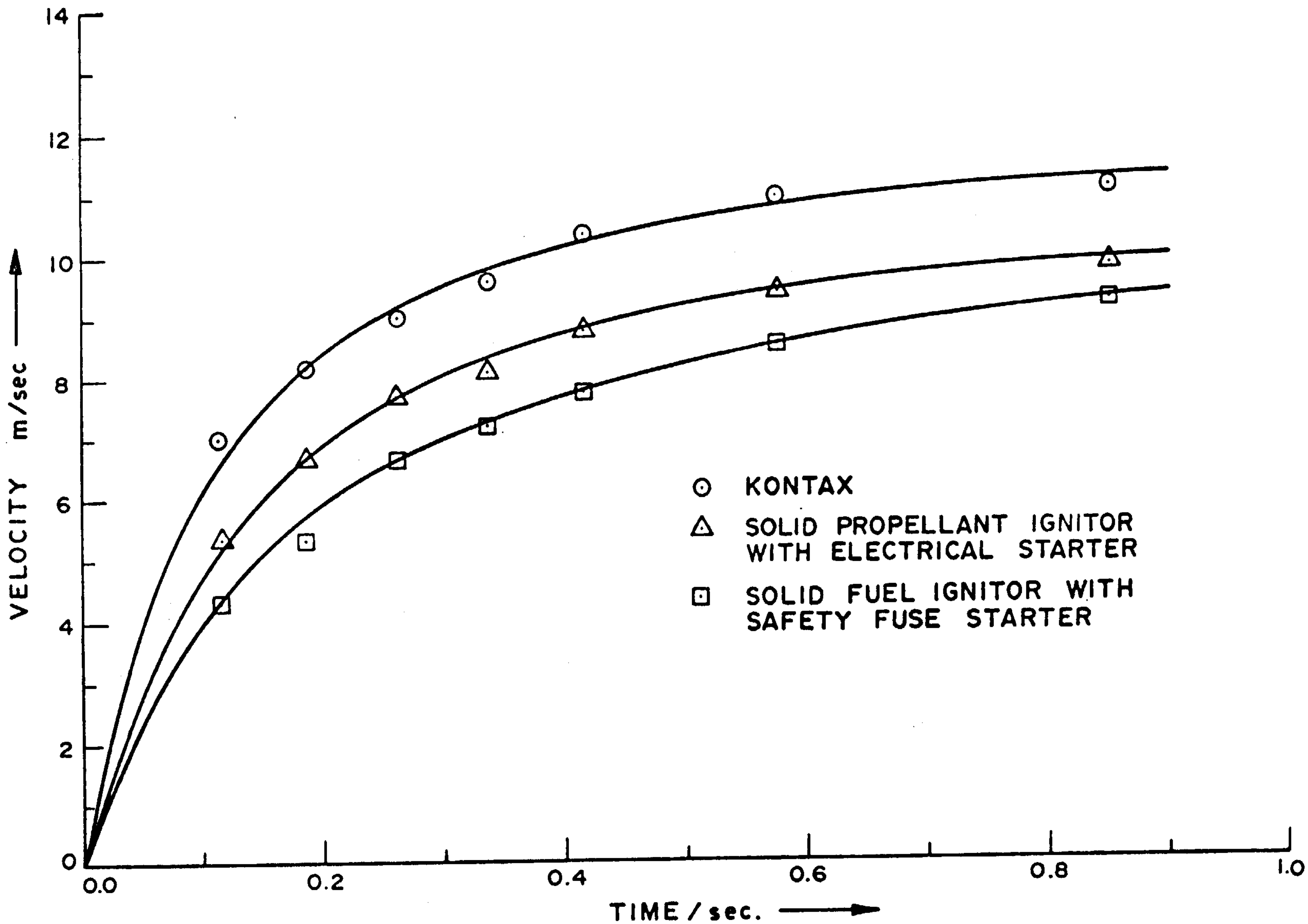


FIGURE 2 FREE FALL VELOCITIES OF IGNITORS

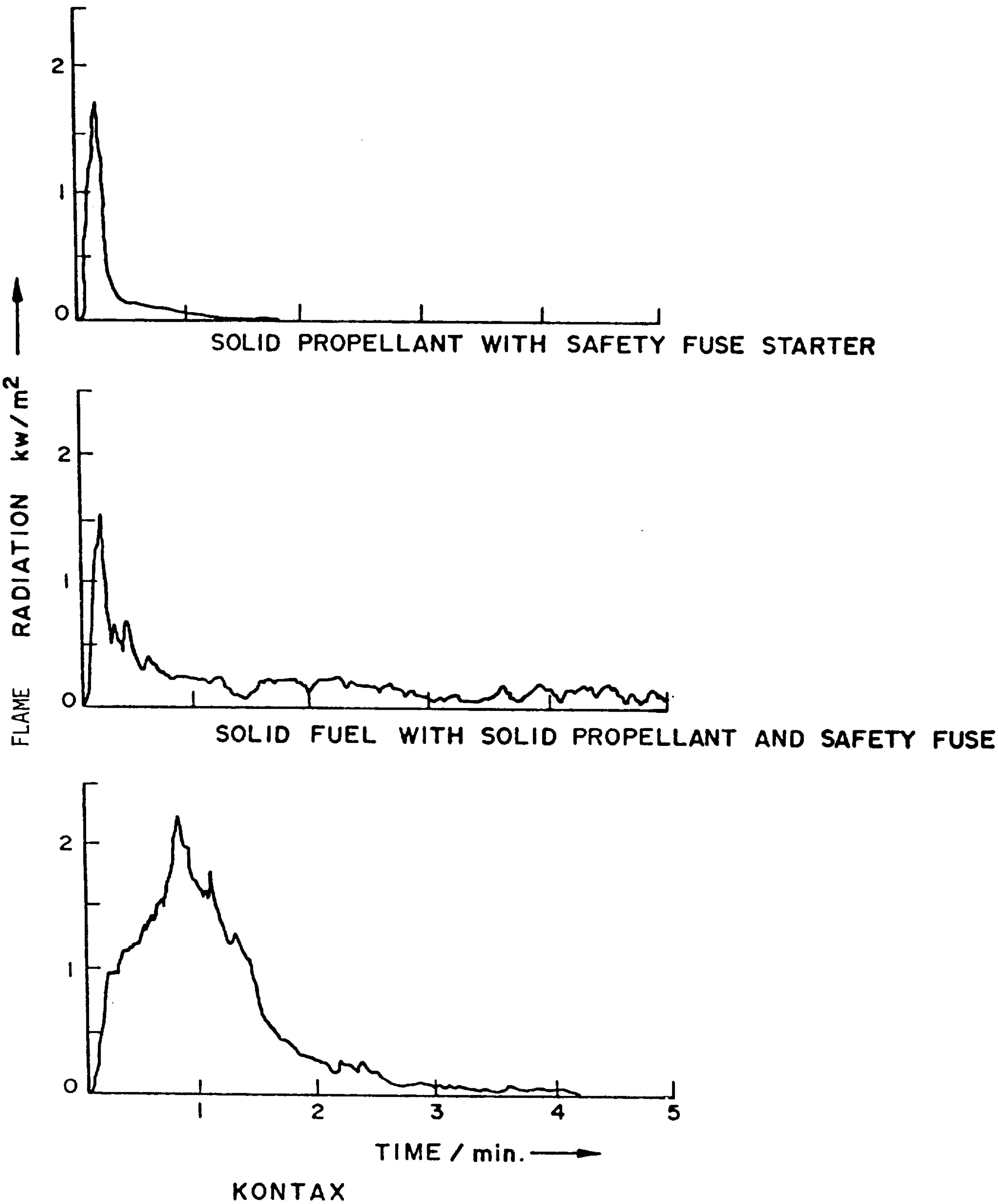


FIGURE 3 FLAME RADIATION FROM THE IGNITORS

(ii) Solid propellant igniters with chemical starters, electrical starters, and fuse wire

(iii) Solid fuel igniters with chemical starters and fuse wire.

5.3 Discussion and Summary

Ignition probabilities of the igniter and starter combinations from the air-deployment tests are shown in Table 4. Solid fuel and solid propellant igniters equipped with safety fuses had the highest ignition probabilities (80% for both combinations) since the safety fuses were the most reliable means to activate these igniters. Solid fuel and solid propellant igniters equipped with chemical starters (sodium plus calcium carbide) had lower ignition probabilities (78% and 67%, respectively) since the sodium in the chemical starter occasionally failed to react vigorously enough with water (after oil contact). Solid propellant ignitiers equipped with electrical starters had a low ignition probability (60%), since the electrical starter was occasionally damaged by the landing impact. Kontax igniters also had a low ignition probability (60% in these runs), since their relatively large size and weight caused them to land "hard" on the slick, thus splashing oil away from the igniter. Calcium hydroxide foam (produced by the reaction of calcium carbide with water) formed about the igniter and often prevented oil from returning to the igniter. Kontax igniters equipped with gasoline performed better in these tests, (having ignition probabilities of 80%), since gasoline spilled over the slick served to make oil ignition easier, and allowed the flames to spread over the calcium hydroxide barrier.

When the factors of availability, shelf life, size, weight, cost, and safety factors were taken into consideration (considered on a scale of one to ten in Table 5), the devices were ranked as follows:

1. Solid fuel with fuse wire
2. Solid propellant with fuse wire
3. Solid fuel with chemical starter
4. Solid propellant with electrical starter

   and

   Solid fuel with electrical starter
5. Solid propellant with chemical starter

TABLE 4

IGNITION PROBABILITIES FROM AIR DEPLOYMENT TEST

| Igniter | Starter | No. of Successful Runs | No. of Failures | Total No. of Runs | Ignition Probability (percent) |
|---|---|---|---|---|---|
| Kontax | Self-contained | 3 | 2 | 5 | 60 |
| Kontax plus Gasoline | Self-contained | 4 | 1 | 5 | 80 |
| Solid Fuel | Chemical | 7 | 2 | 9 | 77.7 |
| Solid Fuel | Fuse Wire | 8 | 2 | 10 | 80 |
| Solid Propellant | Chemical | 6 | 3 | 9 | 66.7 |
| Solid Propellant | Electrical | 3 | 2 | 5 | 60 |
| Solid Propellant | Fuse Wire | 4 | 1 | 5 | 80 |

TABLE 5

IGNITERS EVALUATION AND RANKING

| IGNITER TYPE | IGNITION PROBABILITY (Static) | | IGNITION PROBABILITY (Air-Deployment) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | FRESH OIL | AGED OIL | FRESH OIL | AGED OIL | AVAIL-ABILITY | SHELF LIFE | SIZE & WEIGHT | COST | DEPLOYMENT SAFETY FACTOR | TOTAL | RANKING |
| KONTAX | 10 | 10 | 10 | 6 | 6 | 6 | 4 | 5 | 5 | 62 | 7 |
| KONTAX + GASOLINE | 10 | 10 | 10 | 8 | 6 | 6 | 4 | 5 | 4 | 63 | 6 |
| SOLID PROPELLENT PLUS CHEMICAL STARTER | 10 | 9 | 10 | 6 | 6 | 6 | 5 | 7 | 6 | 65 | 5 |
| SOLID PROPELLENT WITH ELECTRICAL STARTER | 10 | 10 | 9 | 7 | 5 | 6 | 5 | 5 | 9 | 66 | 4 |
| SOLID PROPELLENT WITH FUSE WIRE | 10 | 10 | 10 | 8 | 7 | 9 | 5 | 10 | 1 | 70 | 2 |
| SOLD FUEL WITH CHEMICAL STARTER | 10 | 9 | 10 | 7 | 6 | 6 | 5 | 7 | 6 | 68 | 3 |
| SOLID FUEL WITH ELECTRICAL STARTER | 10 | 9 | 9 | 7* | 5 | 6 | 5 | 5 | 10 | 66 | 4 |
| SOLID FUEL WITH FUSE WIRE | 10 | 9 | 10 | 8 | 8 | 10 | 5 | 10 | 1 | 71 | 1 |

*Assumed, since this combination was not actually tested in air deployment tests.

6. Kontax and gasoline
7. Kontax.

Flame radiation intensity and duration are shown in Figure 3 for each type of igniter fuel. Free-fall velocities and impact velocities of the igniters are shown in Figure 2.

## 5.4 Suggestions For Future Research

1. The D.N.D. (Department of National Defence) flare is known to react exothermically upon contact with This flare should be tested as an air-deployable igniter for oil slicks.

2. Although the sodium and gasoline igniter was not effective in the static test runs, its simple design, small size, and light weight justify further development. Igniters employing kerosene, gasoline, and lighter fluid as fuels should be tested with the following chemical starters:

(a) Potassium, which reacts exothermically upon water contact

(b) Iron-magnesium, copper-magnesium, and nickel-magnesium alloys, which react exothermically upon contact with salt water (Anonymous, 1977).

3. Igniters using calcium carbide as a fuel should be redesigned and tested.

## REFERENCES

American Society for Testing and Materials (ASTM), "Standard Method of Test For Flash and Fire Points by Cleveland Open Cup", American National Standards Institute designation D92-72 (1972).

Anonymous, "Magnesium Alloys That Hold Potential for Several Undersea Uses", Inside R and D, Vol. 6, No. 31, pp. 1, (August 3, 1977).

Anonymous, "Oil Spills Can Be Burned", Offshore, Vol. 29, No. 11, pp. 43, (October, 1969).

Energetex Engineering, "Ignition and Burning of Crude Oil on Water Pools Under Arctic Spring Time Conditions", submitted to Canadian Marine Drilling Ltd., Calgary, Alta., (December, 1977).

Herschmiller, D.W., and Revel, R.D., "Terrestial Spillage of Oil in the Arctic", AIChE Symposium "Water - 1974: Industrial Waste Treatment", Vol. 70, No. 144, pp. 254-260, (1974).

McLeod, D.L., and McLeod, W.R., "Measures to Combat Arctic and Subarctic Oil Spills", Journal of Petroleum Technology, pp. 269-278, (March, 1974).

Norcor, "The Interaction of Crude Oil With Arctic Sea Ice", Beaufort Sea Technical Report #27, submitted to the Department of the Environment, Victoria, B.C., (1975).

Smith, J.W., "Problems In Dealing With Oil Pollution on Sea and Land", Institute of Petroleum Journal, Vol. 54, No. 539, pp. 358-366 (November, 1968).