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TECHNICAL NOTE

MRL-TN-525

SOME PROPERTIES OF AUSTRALIAN PRODUCED EXPLOSIVE COMPOSITION H-6

L. McVay and T. Bussell

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ABSTRACT

The report describes an investigation to characterise the physical nature of cast H-6 and assess its stability and explosive properties. Scanning electron and optical microscopes were used to determine the aluminium and RDX distribution in the TNT matrix while explosive stability was assessed from the results of vacuum stability and temperature of ignition tests and differential scanning calorimetry. H-6 sensitivity was assessed from the results of the gap test, Rotter impact test, train test and jet sensitivity test. Some detonation parameters were determined experimentally and compared to BKW code estimates.

The study showed that Australian produced H-6 exhibited similar stability and sensitivity characteristics to Composition B and that the results supported data published for equivalent US tests. The aluminium was shown to be well distributed within the RDX/TNT system with only a small tendency to aggregate.

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CONTENTS

SOME PROPERTIES OF AUSTRALIAN PRODUCED EXPLOSIVE COMPOSITION H-6

1. INTRODUCTION

The aluminised explosive H-6 was developed in the USA to produce an explosive filling based on RDX/TNT but with enhanced blast characteristics [1]. Currently H-6 is made in Australia at St Marys Munitions Filling Factory (MFF) New South Wales, as a fill for Mk 82 and Mk 84 bombs. H-6 also has wide usage in the USA and UK as a torpedo filling and consequently is a potential candidate for a similar role in Australia.

This report describes an investigation to characterise the physical nature of cast H-6 and to determine its explosive properties particularly stability and sensitivity. The stability measurements were made using tests readily available at MRL and designed to provide information to assist understanding the hazard profile of the explosive during fabrication, evaluation and use. The sensitivity tests selected were also readily available at MRL and provide information on the hazard profile and performance characteristics. Further performance data was obtained from some detonation parameter measurements. The results are compared to USA H-6 data and, where appropriate, to results from similar tests on Composition B because of the wide experience obtained in handling and fabricating charges made from Composition B.

2. CHARACTERISATION

2.1 Charge Preparation

Unless otherwise stated test samples were prepared as follows. Castings were made by melting the H-6 biscuit as supplied by MFF and pouring into a 51 mm diameter, preheated mould. The removal of the casting headers and machining of the samples to size were carried out by remote control using hardened steel tools. The

aluminium in the H-6 considerably reduced the useful life of the cutting tools compared to Composition B.

2.2 Composition

The composition of H-6 was determined by the wet method described in specification MIL-E-22267A.

Prior to analysis, a sample of the biscuit was ground with a porcelain mortar and pestle to produce a homogeneous sample. Two determinations were undertaken and the mean values are listed in Table 1 together with comparisons with the nominal composition [1,3] and the specifications limits.

TABLE 1

Chemical Composition of H-6

Component	Nominal Composition % by weight	Specification Limits % by weight	Measured Value % by weight
TNT	29.5	29.2 ± 3.0	27.7
Aluminium	21.0	21.0 ± 3.0	22.7
RDX & Nitrocellulose	44.0	45.1 ± 3.0	43.1
Calcium Chloride	0.5	0.7 ± 0.3	0.4
Wax	5.0	4.7 ± 1.0	6.1

Generally the measured values fall within the specification limits. Note the wax value was not determined experimentally but by difference and is therefore influenced by the accumulated errors for the measurements of the other ingredients. Thus it should not be assumed that the sample's wax content was outside the specification maximum.

2.3 Density

The density of H-6 was determined by weighing machined cylindrical samples.

The cylinders had masses in the range 95 to 101 g, with heights and diameters between 5 to 6 cm and 3.7 to 3.9 cm respectively. The mean density calculated for 14 samples was 1.74 Mg/m^3 which is 97% of the theoretical maximum density (1.79 Mg/m^3) and is in agreement with the quoted US value [18].

2.4 Distribution of RDX and Aluminium Particles

A study of the RDX and aluminium distribution within the TNT matrix was undertaken by optical microscopy and scanning electron microscopy (SEM).

The most satisfactory method for revealing the microstructure of H-6 for microscopy was to prepare the cast specimen by the three-stage polishing sequence as follows:

1. primary polishing with wet "used" P400A silicon carbide paper for approximately 5 minutes, with regular cleaning of the paper;
2. intermediate polishing with wet "used" P1200A silicon carbide paper for 5 to 10 minutes, with regular cleaning of the paper;
3. finishing on pure velvet using laboratory reagent magnesium oxide as an aqueous paste.

To highlight the TNT matrix, a 1 to 5 second etch with bromoform was required.

2.4.1 Scanning Electron Microscopy

A Cambridge S250 Mark 2 Scanning Electron Microscope (SEM) was used to study the TNT matrix and RDX and aluminium distribution in the explosive because of the limitations found with optical microscopy (see Section 2.4.2). The SEM and normal operating techniques are described in detail in references 11 and 12.

The technique for preparing the H-6 samples was to coat the polished specimen (see Section 2.4) with a layer of vaporised gold in order to produce a conductive surface. This coating was discontinuous, and less than 0.8×10^{-9} m thick. The sample was attached to a mushroom shaped aluminium sample stub, placed under vacuum in a large bell jar, and spun while adjacent gold wire was electrically vapourised. Spinning the sample virtually eliminated "shadowing" of the coating on uneven surfaces. Coating time was limited to ten minutes in order to minimise TNT sublimation. TNT possesses a high vapour pressure and exposure to vacuum causes sublimation, pitting the surface.

Other important features when using the SEM to study crystallography in explosives are as follows:

1. The sample size is kept to a minimum (approximately 20 mm square and 6 mm thick) to minimise any effects from unwanted decomposition.

2. The sample, when placed in the SEM, is continually scanned to avoid beam concentration on a fixed position. This is to minimise vapourisation of the explosive and cracking of the gold coating.

3. A scanned section of the sample is frozen on a VDU and pictures are taken from this image.

SEM photomicrographs were taken of polished and etched H-6 specimens at several magnifications.

Figures 1 and 2 are photomicrographs of the H-6 showing aluminium and RDX distribution within the TNT matrix. In these figures the aluminium particles exhibit a lighter colour while the RDX crystals are darker with a rounded shape. The aluminium particles are of similar size and distribution to the RDX and are well distributed with only a small tendency to aggregate.

Figure 3 shows a closer view of the shape and size of the aluminium and RDX particles. Figures 3 and 4 are under the same magnification but the latter has been etched with bromoform. The TNT structure, which has a needle shape, can be seen in both Figures 3 and 4.

Figure 5 is of polished H-6 under x 500 magnification showing a section of an aluminium particle with a film of wax to the right of the particle overlapping a section of a RDX crystal. This photomicrograph also shows RDX crystals, together with the TNT matrix.

In Figure 6 the H-6 has been polished and etched with the magnification being x 200. The alignment of the TNT structure is clearly visible in both Figures 5 and 6.

Figures 7 and 8 are photomicrographs of H-6 which has been polished and etched - they show an enlarged view of the TNT structure.

These photomicrographs show that the distribution of RDX within the TNT matrix is similar to that reported by Thorpe and Smith for Composition B [11].

2.4.2 Optical Microscopy

Optical microscopy employed a Leitz Ortholux Microscope with 3.8 and 11 objective lenses and a x 10 eyepiece with a 35 mm camera attachment.

The technique for preparing the H-6 for optical microscopy is described in Section 2.4.

A photomicrograph of the H-6 is shown in Figure 9. This figure shows the aluminium particles (light in colour) together with the rounded RDX crystals (dark in colour). Comparing Figures 1-8 to Figure 9, the SEM produced photomicrographs providing more information on the aluminium and RDX distribution and clearly defining the TNT structure.

The TNT structure of the H-6 is similar to that of Composition B described in reference 11.

3. EXPLOSIVE PROPERTIES

3.1 Stability

3.1.1 Vacuum Stability

The vacuum stability test is a widely recognised method for assessing the stability of explosives (Chemical Inspectorate Method EB26).

In the test 5 g of ground H-6 was weighed into the heating tube of the vacuum apparatus and placed in a bath (Figure 10) maintained at 100°C for a period of 40 h. At fixed times during the test, readings were taken of the volume of evolved gas. Results for two samples are given in Table 2.

TABLE 2

Measure of Gas Evolved from a 5 g Sample

Time (hours)	Sample 1 Gas Evolved (ml)	Sample 2 Gas Evolved (ml)	Average Gas Evolved (ml)
16.25	0.00	0.10	0.05
19.50	0.11	0.14	0.12
21.17	0.11	0.14	0.12
24.33	0.14	0.18	0.16
40.00	0.18	0.26	0.22

Table 2 shows that the average volume of gas evolved at STP after 40 h was 0.22 ml which compares favourably with the value for Composition B of between 0.1 and 0.2 ml.

Direct comparison of the H-6 result with the literature data [1-3] was not possible since the tests were carried out under different conditions. However, the literature data gives values for H-6 which are similar to Composition B and are therefore in accord with the pattern of results obtained in this study.

3.1.2 Temperature of Ignition

Temperature of ignition is essentially a stability test that indicates the temperature at which a material inflames, explodes or undergoes rapid combustion (shown by a puff of smoke) [13].

In the test, 0.2 g of ground H-6 was weighed in borosilicate test tubes and heated in a steel block (Figure 11) the temperature of which is controlled to rise at a steady rate of 5^{o} per minute.

The test was performed in duplicate and both samples inflamed at a temperature of 205^{o}C.

For comparison purposes the temperature at which Composition B ignites is 193^{o}C. These values agreed with US values for the "autoignition temperature" for H-6 of 200^{o}C and for Composition B of 194^{o}C.

3.1.3 Differential Scanning Calorimeter

Differential scanning calorimetry (DSC) [8] allows a more detailed examination of the thermal properties of materials than the routine tests reported in sections 3.1.1 and 3.1.2. The direct calorimetric measuring principle of the instrument (Perkin-Elmer DSC-2C Differential Scanning Calorimeter) requires that each sample holder has a built-in heater and temperature sensor (Figure 12).

In the test the H-6 was finely ground and two samples of masses 5 mg and 4.8 mg were weighed directly into aluminium pans, and lids placed (but not crimped) over the samples.

Both the reference holder (compartment containing the empty pan and lid) and the sample holder (compartment containing the sample filled pan and lid) were continuously purged with nitrogen gas throughout the DSC scans. The nitrogen flow rate was typically 20-25 ml min^{-1}.

Calibration of the instrument was carried out in accordance with the following standards [8],

indium (m.p. 429.8 K, heat of fusion 28.5 Jg^{-1})
tin (m.p. 505.1 K)

When a transition such as melting, boiling, dehydration or crystallization occurs in the sample an endothermic or exothermic reaction takes place. The change in

power required to maintain the sample holder at the same temperature as the reference holder during the transition is recorded as a peak. The transition temperature is located and the peak area indicates the total energy transfer to or from the sample. Details of the technique as applied to the examination of energetic materials have been widely reported [8 to 10]. The thermograms are shown in Figures 13 and 14 and exhibit an endothermic peak corresponding to melting and an exothermic peak corresponding to decomposition. The heats of transition (ΔH) for duplicate determinations of these changes are given in Table 3. The average temperature for the endothermic peak was 353.02 K (79.82°C) with a mean ΔH of 26.99×10^3 J/kg; this corresponds to the melting of TNT. The average temperature for the exothermic peak was 514.52 K (241.3°C) with a mean ΔH of -874.54×10^3 J/kg. The exotherm is due to thermodecomposition which is likely to be TNT but may be complicated by the presence of RDX. It is not known from this limited study if the aluminium takes an active role.

TABLE 3

DSC Data for H-6

Type of Transition	Explosive Mass mg	Maximum Temp. K	Heat of Transition J/kg
Melting (Sample 1)	0.48	352.94	26.99×10^3
Melting (Sample 2)	0.55	353.11	27.24×10^3
Decomposition (Sample 1)	0.48	516.5	-926.17×10^3
Decomposition (Sample 2)	0.55	512.53	-822.91×10^3

3.2 Sensitivity

3.2.1 Small Scale Gap Test

Small scale gap test (SSGT) is used for assessing the shock sensitivity of explosives.

Basically the test assembly consists of four components.

1. An explosive donor charge
2. A brass shock attenuator (gap)
3. An acceptor charge (the explosive under test)
4. A mild steel witness block for detecting the type of event.

The components are assembled with the aid of a jig. The sensitivity of the explosive is expressed as the thickness of the brass gap which produces a 50% probability of detonation in a series of trials - this is achieved by varying the gap thickness in a prescribed manner to produce a regular pattern of detonations and failures. The thicker the gap the greater the sensitivity of the test explosive to shock.

A more detailed description of the test and the components required for the experiments is found in Reference 5. Table 4 lists MRL SSGT data for H-6 and Composition B. These results suggest that the addition of a large amount of aluminium (~ 22%) to the cast RDX/TNT system does not appreciably change the shock sensitivity.

TABLE 4

Shock Sensitivity Results Obtained Using the MRL SSGT

Explosive	Density Mg/m^3	Shock Sensitivity	
		$M_{50\%}$ mm	$\sigma M_{50\%}$ mm
H-6	1.74	0.42	0.0065
Composition B	1.65	0.40	0.01

3.2.2 Rotter Impact Test

This test measures the sensitivity of an explosive sample to impact by comparing the median drop height of a given mass to produce an explosion in 50% of a series of trials to that for the corresponding drop height for a standard explosive. The value is quoted as the Figure of Insensitiveness of the test explosive (F of D. Thus the lower the F of I value the more sensitive the explosive is to impact.

The median drop heights for the standard and the sample are determined by the "Bruceton Staircase" technique using the Rotter impact machine with a 5 kg weight (Figure 15) [13].

The F of I of H-6 was determined to be 180 as compared with the Composition B value of 140. The lower sensitivity of H-6 is attributed to the greater proportions of inerts present in the composition. This pattern of results is similar to that Reported for USA data using the LLNL drop weight test [4].

3.2.3 Train Test

The train test [13] assesses the ability of an explosive to support steady burning and the results are reported as falling into one of the following categories:

1. Fails to ignite.
2. Ignites but fails to support train for more than .... centimetres.
3. Ignites but supports train fitfully.
4. Ignites and supports train steadily throughout.
5. Ignites and supports train vigorously throughout.
6. Explodes.

In the test an unconfined train of ground H-6 was ignited at one end by a naked flame (Figure 16) and the following observations were made:

1. The flame had a pale yellow centre surrounded by an orange halo.
2. Small sparks escaped from the flame front as it burnt along the train.
3. From time to time the flame exhibited small variations in flame intensity. This may have been caused by variations in the sample geometry.
4. The H-6 burnt the full length of the train.

Consequently H-6 was classified as a category 4 explosive in the test. Composition B also exhibits steady burning and hence falls into the same category as H-6.

3.2.4 Sensitivity to High Velocity Jets

The MRL jet sensitivity test was developed to investigate the sensitivity of both bare and covered explosives to high velocity jets. The experimental assembly for assessing covered explosives is shown in Figure 17 and described in detail in References 6 and 7.

The test is based on determining the critical "go-no go" detonation behaviour of the receptor explosive and the pattern of results is analysed statistically.

The sensitivity of the explosive is expressed as critical jet velocity or the thickness of the cover or barrier material which produces a 50% probability of detonation. The H-6 sample comprised two 38 mm diameter machined cylinders 51 mm long and positioned coaxially. Table 5 shows the results on covered H-6 and Composition B. Gap test results (from Table 4) have been included in Table 5 for comparison since both tests are based on a type of shock initiation and so may be expected to produce a similar order of results.

TABLE 5

Jet Sensitivity Values for Steel Covered Explosives

Explosive	Jet Sensitivity		MRL Shock Sensitivity Test
	Critical Steel Cover Thickness $M_{50\%}$ mm	Critical Jet Velocity $M_{50\%}$ mm/μs	$M_{50\%}$ mm
H-6	69.7	4.9	0.42
Composition B	59.8	5.2	0.40

The results from Table 5 indicate that H-6 appears to be a little more sensitive than Composition B.

A flash radiograph of the jet initiation of covered H-6 near the critical condition is given in Figure 18 and clearly shows the reactive bow wave in front of the penetrating jet. The run to detonation was estimated to be 38 mm.

3.3 Detonation Parameters

The detonation parameters of H-6 have been determined experimentally and using the Becker-Kistiakowsky-Wilson (BKW) code [14].

The BKW calculations were undertaken to provide a full range of detonation parameters. The validity of using the code for explosives like H-6 with a high aluminium content was checked by comparing the predicted detonation velocity with the experimentally determined value. The BKW data are given in Table 6.

3.3.1 Velocity of Detonation

The experimental detonation velocity was determined electronically by incorporating a series of ionisation probes (switches) in a stack of 38 mm diameter H-6 pellets [15]. The pellets were nominally 25 mm long but each was measured and cleaned prior to assembly. Cleaning involved washing with distilled water and drying. Surface cleaning was required since H-6 contains calcium chloride whose deliquescent nature produces a conductive layer on the pellet surface. Two measurements were made each using 10 H-6 pellets. The rounds were initiated by an exploding bridgewire detonator (EBW) and the ionisation probes were progressively closed by the detonation front. These pulses were relayed to a digital recorder and computer for examination and calculation. After excluding the portion of the measurement relating to the detonation

build-up the steady state velocity was calculated from the events for 9 probes. The two experiments produced velocities of detonation of 7.355 km/s and 7.294 km/s.

Some BKW data is given in Table 6.

TABLE 6

Detonation Parameters of H-6

	Density Mg/m^3	V of D km/s	Detonation Pressure GPa
BKW Calculations	1.739	7.31	23.3
MRL Experimental Data	1.739	7.324	23.32
USA Experimental Data	1.71	7.19 [a]	22.1 [c]
	1.76	7.90 [b]	27.5 [c]
	1.76	7.4 [d]	24.5 [d]

a. from Reference 4,
b. from References 2 and 4,
c. see text,
d. from Reference 17.

The mean experimental velocity of detonation value is given in Table 6 together with USA experimental data. The detonation pressures, P, marked by the superscript 'c' were estimated using the experimental velocity of detonation, D, and the relationship [17];

$$P = \frac{1}{1 + \gamma} \rho D^2 \qquad (1)$$

where ρ is the explosive density, and γ the adiabatic exponent at the Chapman-Jouguet (CJ) point which can be approximated to 3 for military explosives close to the theoretical maximum density.

Table 6 shows excellent agreement between the BKW and MRL experimental detonation velocity values. This supports use of the code for this type of aluminised explosive. When density differences are taken into account there also appears to be good agreement between the MRL and USA experimental data with the exception of the second set of USA data.

3.3.2 Plate Dent Measurements

Plate dent measurements were carried out to estimate the CJ detonation pressure. The test method and assembly was based on that developed at Los Alamos National Laboratory and described by Smith [19]. A 200 mm high column of H-6 made up from 38 mm diameter by 50 mm long pellets was centrally located on a mild steel block 150 mm diameter by 150 mm thick. The surface of the steel had been surface ground to ensure intimate contact with the explosive. The charge was initiated with an EBW and the depth of dent produced in the steel block by the detonation was measured with a depth micrometer. For comparison purposes a similar test was performed using Composition B. The CJ detonation pressures were estimated from the relationship between dent depth and CJ pressures reported by Pimbly et al [20].

H-6 produced a dent of 6.68 mm which gives an estimated CJ value of 22 GPa - this is similar to the values listed in Table 6. Composition B produced a dent of 7.05 mm with an estimated CJ pressure of 23 GPa. The latter appears a little low when compared to a BKW value of 25.3 GPa [14] and a value of 26 GPa calculated using equation (1) for a density of 1.68 Mg/m^3 and a measured velocity of detonation of 7.77 km/s. This discrepancy is probably due to the less than ideal dent produced by the Composition B detonation. Further experiments, which are to be undertaken, should clarify this.

4. CONCLUSIONS

A variety of tests have shown that Australian produced H-6 exhibits similar stability and sensitivity characteristics to Composition B. Furthermore, the measured values from the tests were similar to data published for equivalent US tests.

The aluminium was shown to be well distributed within the RDX/TNT system with only a small tendency to aggregate. The RDX distribution within the TNT matrix was similar to that reported for Composition B.

A summary of the results from the tests is given in Table 7.

TABLE 7

Summary of Results

Property	Results
Chemical Composition	
TNT	27.7%
Aluminium	22.7%
RDX and Nitrocellulose	43.1%
Calcium Chloride	0.4%
Wax	6.1%
Density	1.74 Mg/m^3
Vacuum Stability	0.22 ml/5 g
Temperature of Ignition	205°C
DSC	
Melting Transition	26.99×10^3 J/kg at 77.82°C
Decomposition Transition	-874.54×10^3 J/kg at 241.3°C
Shock Sensitivity	$M_{50\%} = 0.42$ mm σ $M_{50\%} = 0.0065$ mm
Rotter Impact (F of D	180
Train Test	Ignites and supports train steadily throughout
Jet Sensitivity	
(a) Critical steel cover thickness	$M_{50\%} = 69.7$ mm
(b) Critical jet velocity	$M_{50\%} = 4.9$ mm/μs.
Detonation Velocity	7.324 km/s (measured), 7.31 km/s (BKW)
Detonation Pressure	23.32 GPa (from detonation velocity), 23.3 GPa (BKW)
Plate Dent	6.68 mm, estimated detonation pressure 22 GPa

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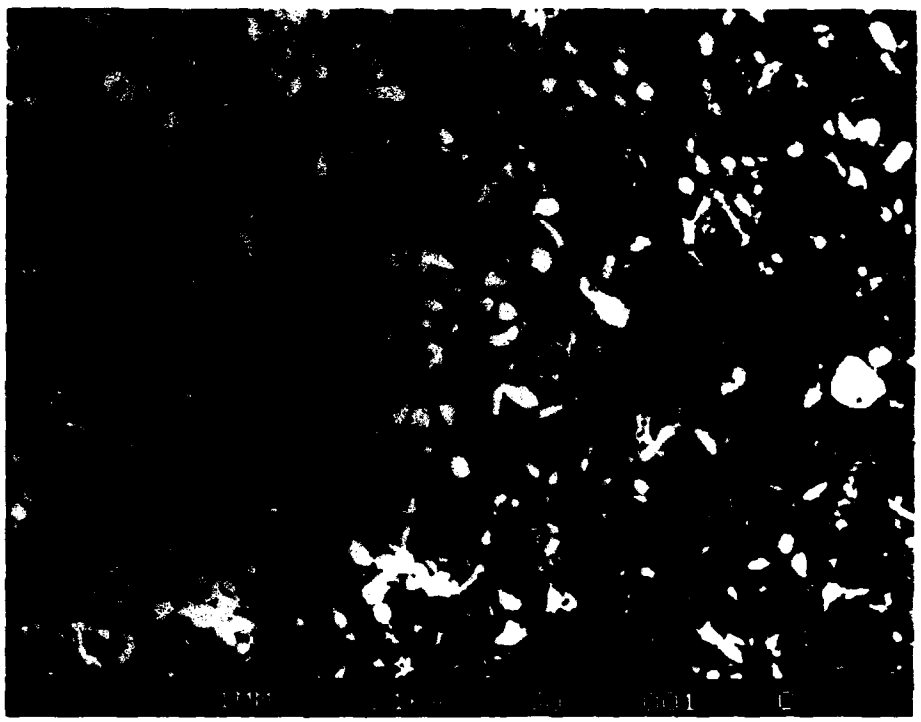


FIGURE 1 H-6 polished and gold coated showing aluminium and RDX distribution x 20.

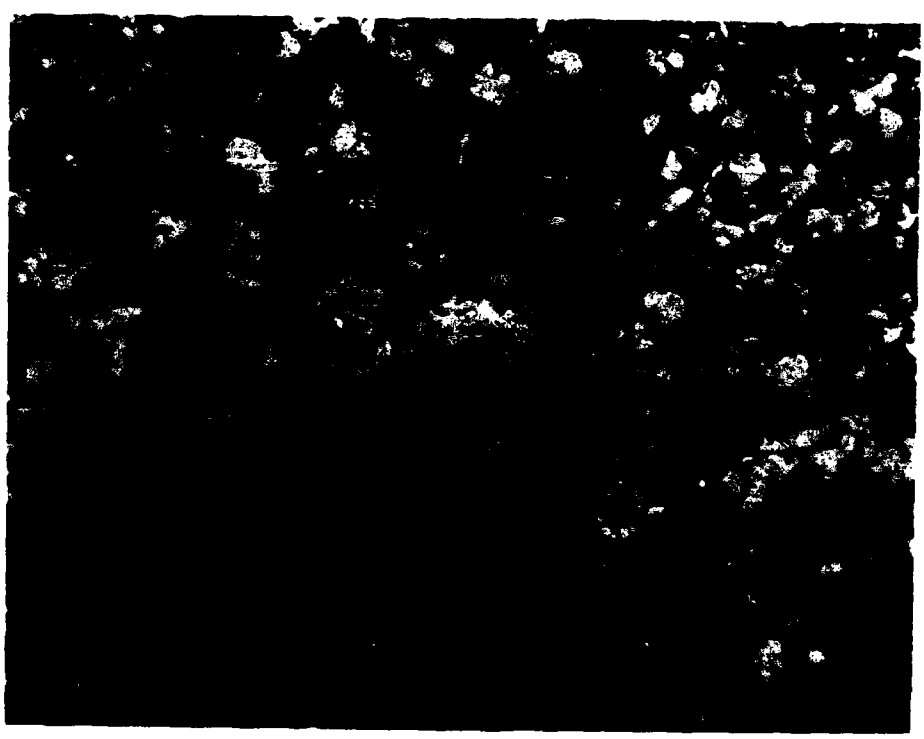


FIGURE 2 H-6 polished and gold coated showing aluminium and RDX distribution x 20.

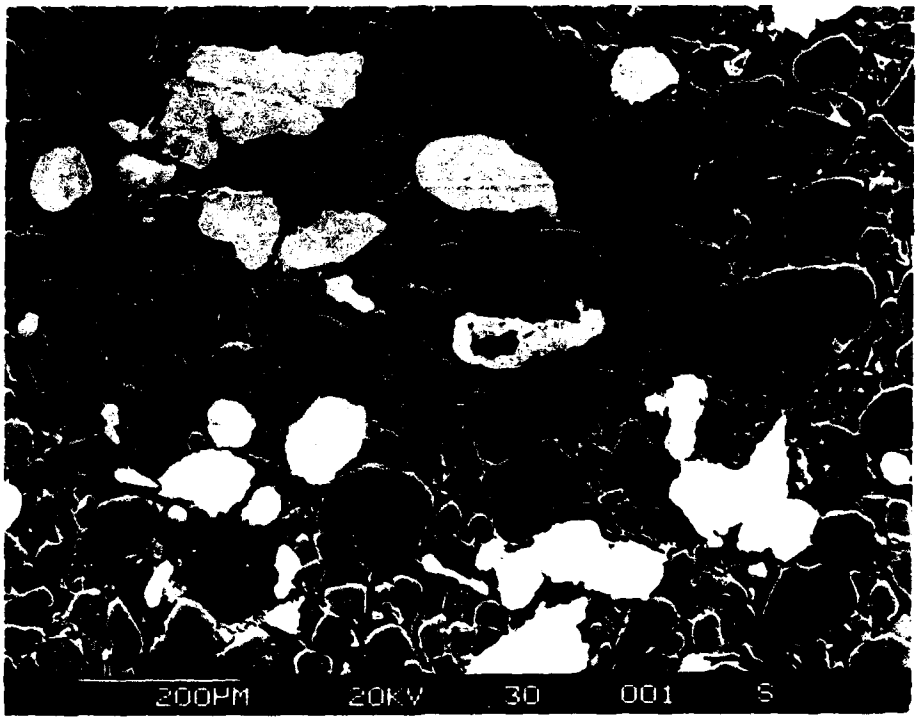


FIGURE 3 Polished (unetched) H-6 x 100

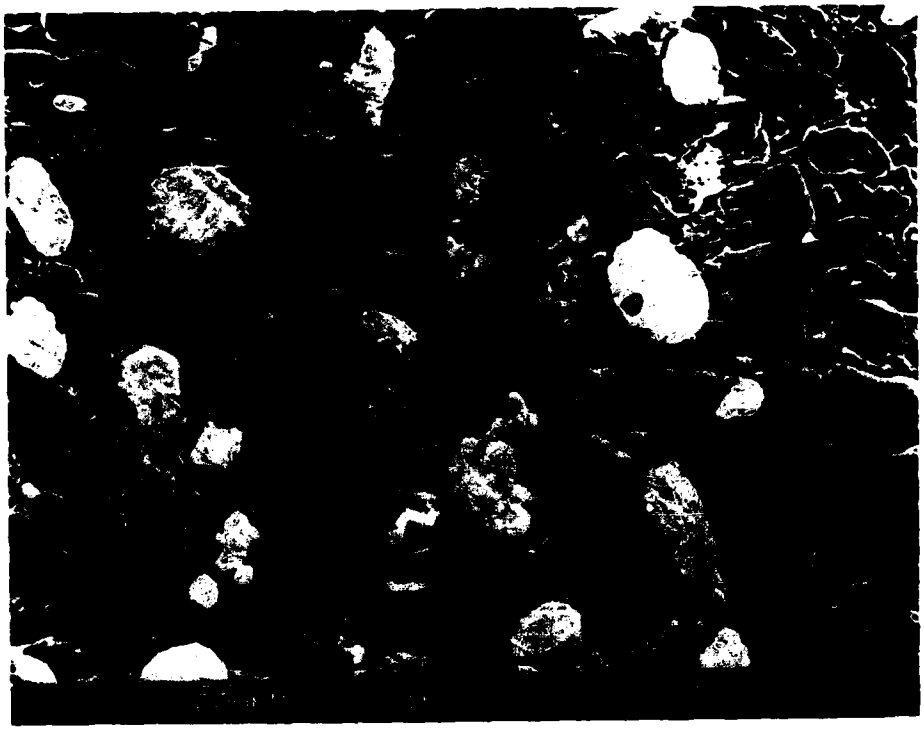


FIGURE 4 Polished and etched H-6 x 100

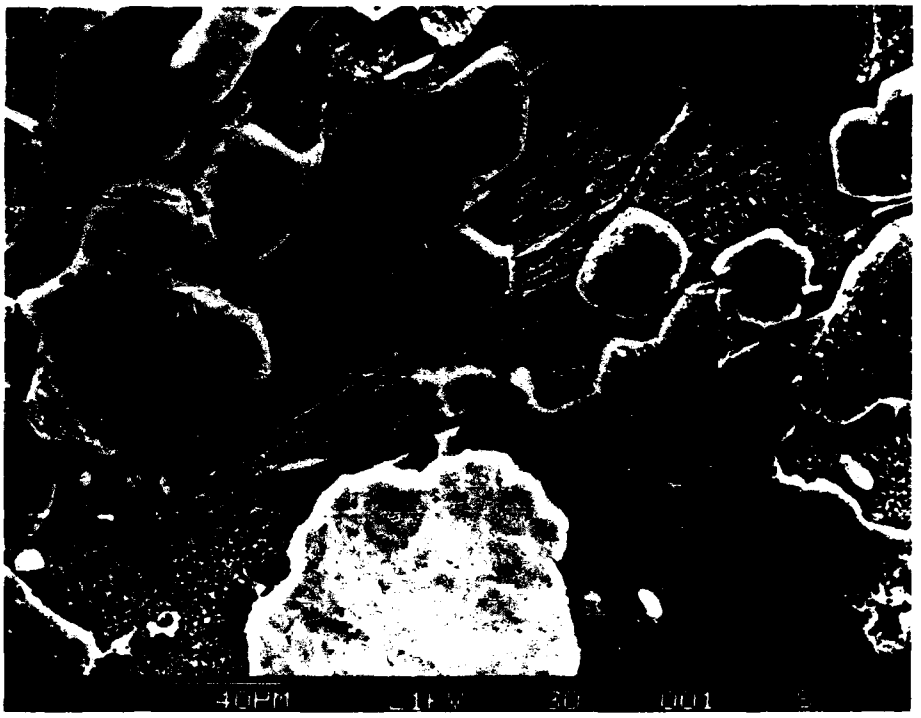


FIGURE 5 Polished H-6 x 500

FIGURE 6 Polished and etched H-6 x 200

FIGURE 7 Polished and etched H-6 x 500

FIGURE 8 Polished and etched H-6 x 500

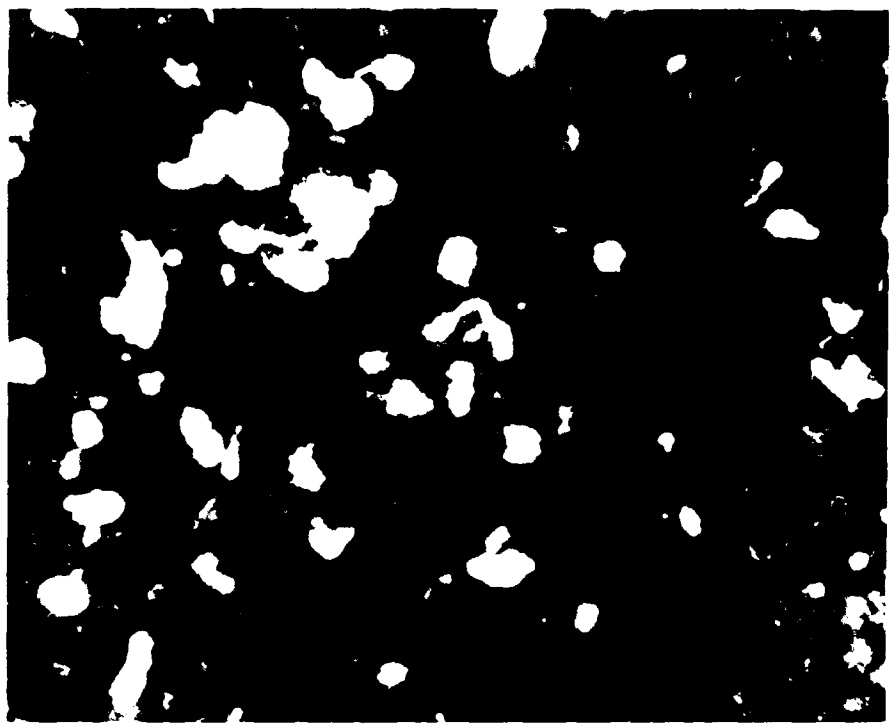


FIGURE 9 Polished and etched H-6 seen under the optical microscope

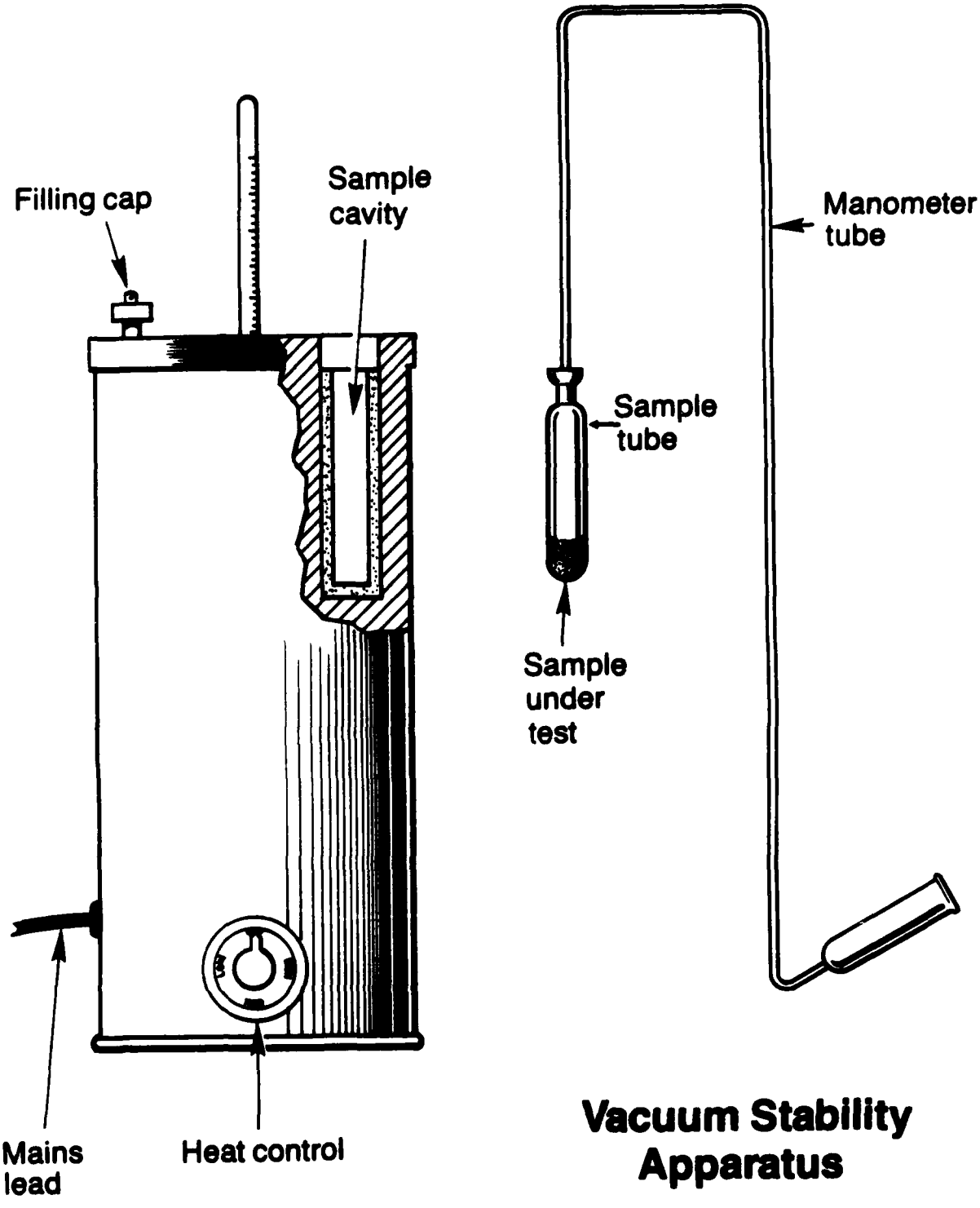
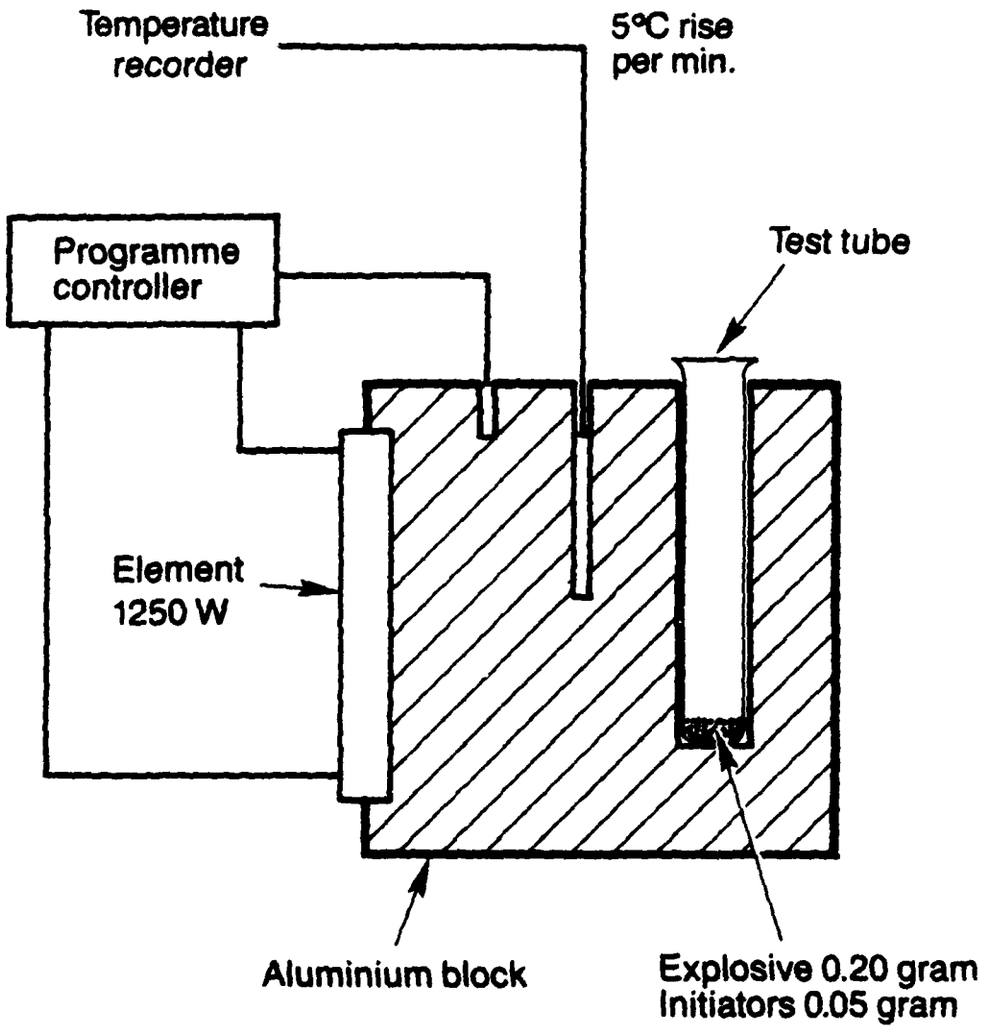

Filling cap
Sample cavity
Manometer tube
Sample tube
Sample under test
Mains lead
Heat control
Vacuum Stability Apparatus
Stability Bath
(Electrically heated — thermostatically controlled)

FIGURE 10



Temperature of Ignition (T of I)

FIGURE 11

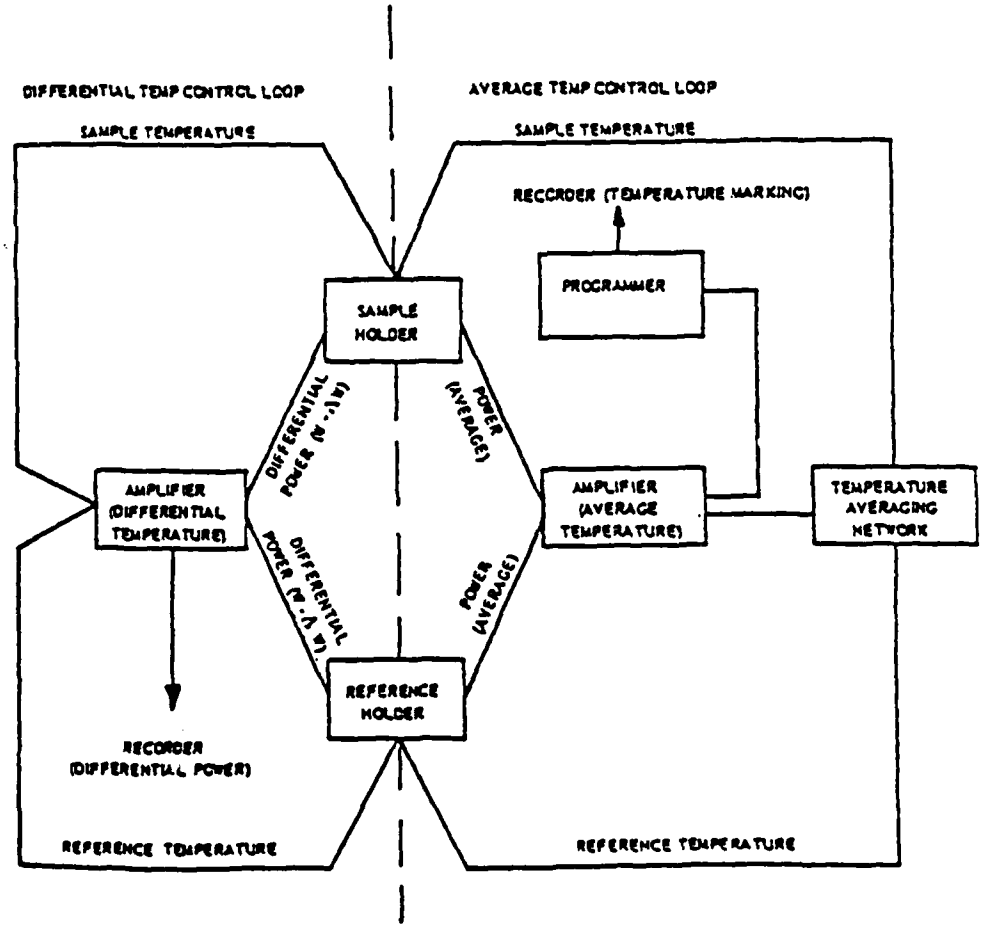


FIGURE 12 Model DSC-2 Block Diagram

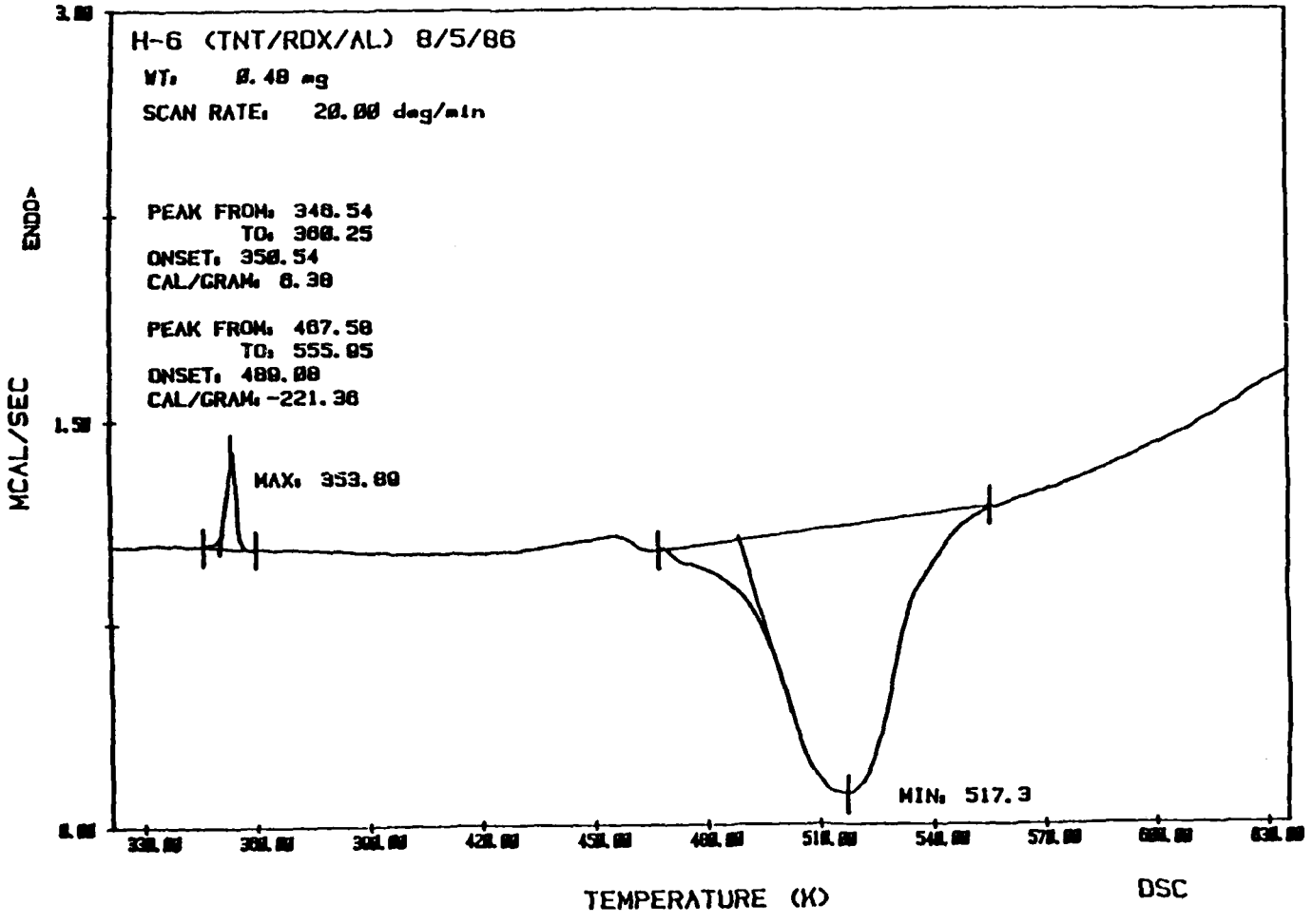


FIGURE 13 Thermogram of H-6

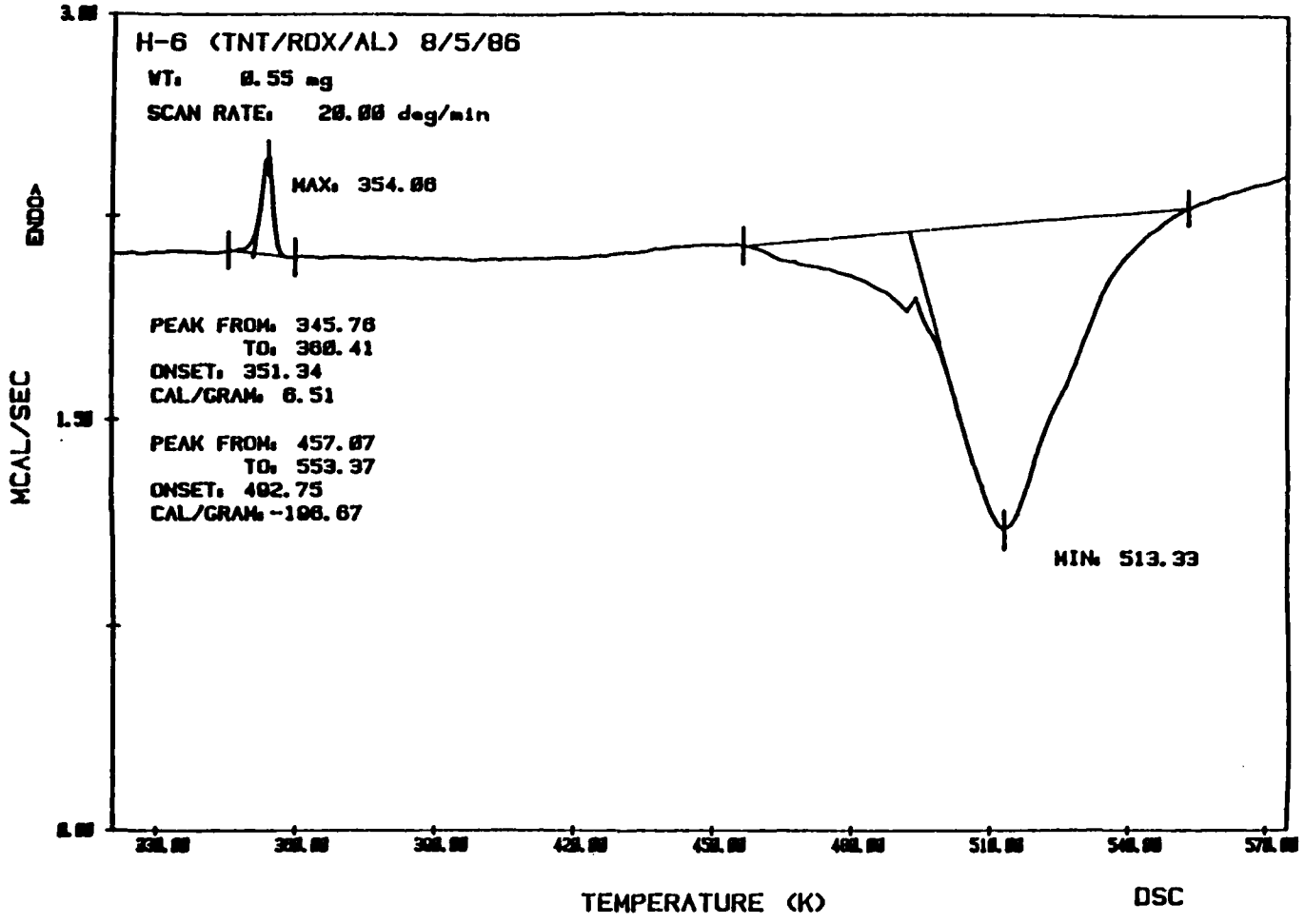
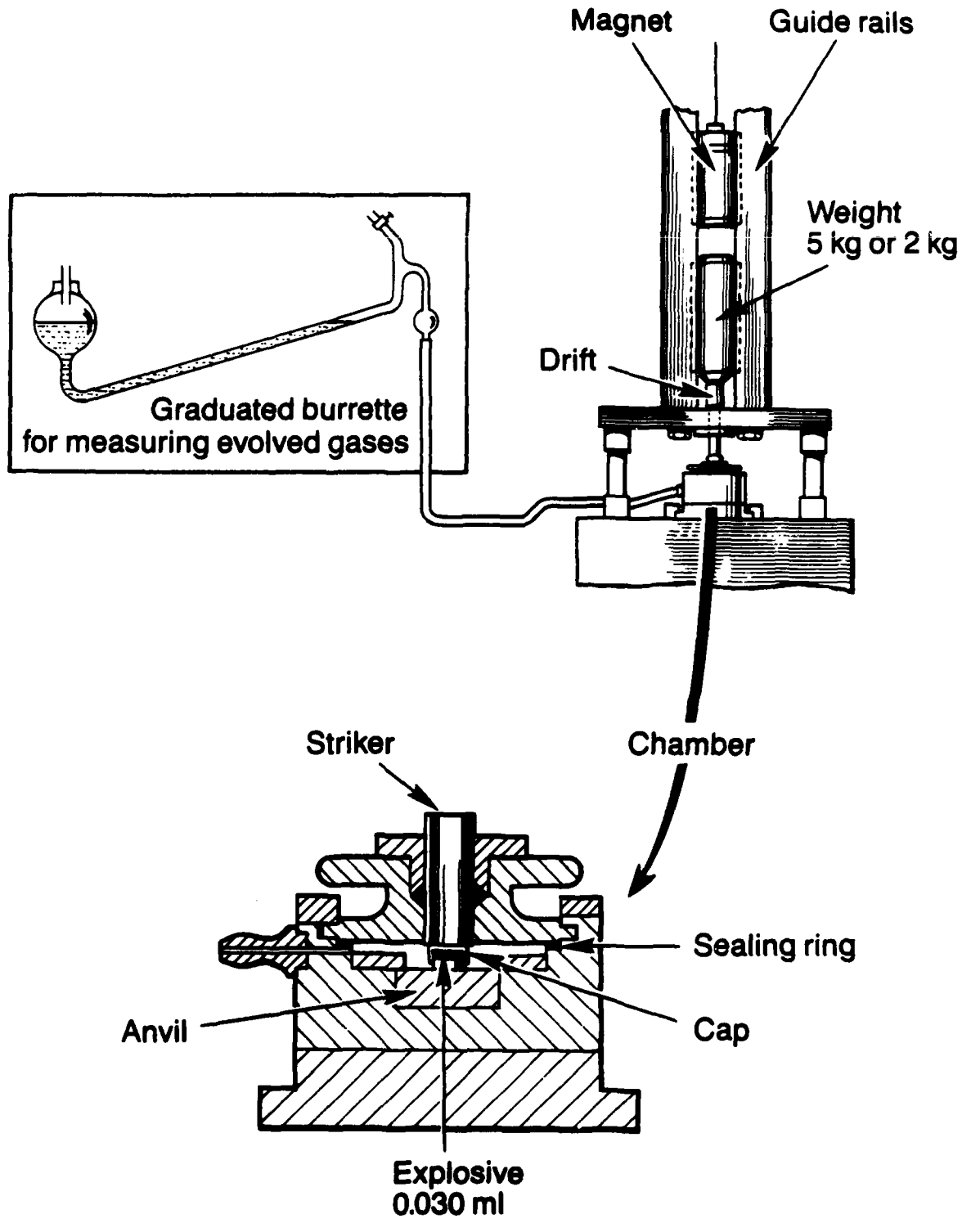
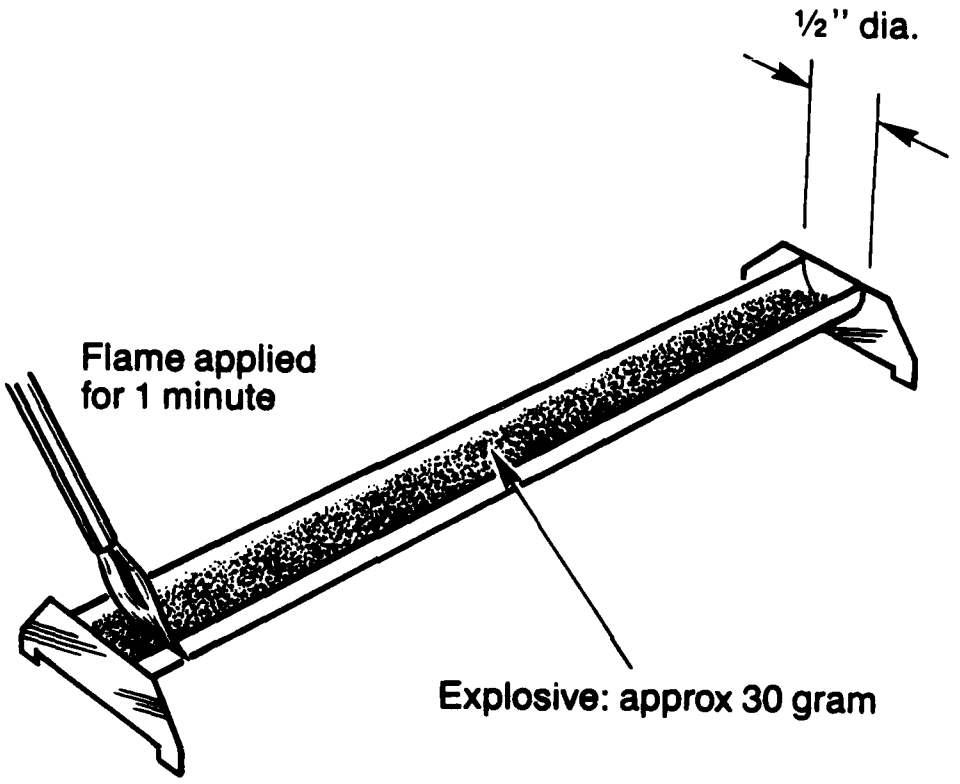


FIGURE 14 Thermogram of H-6



Rotter Impact Test (F of I)

FIGURE 15



Train Test

FIGURE 16

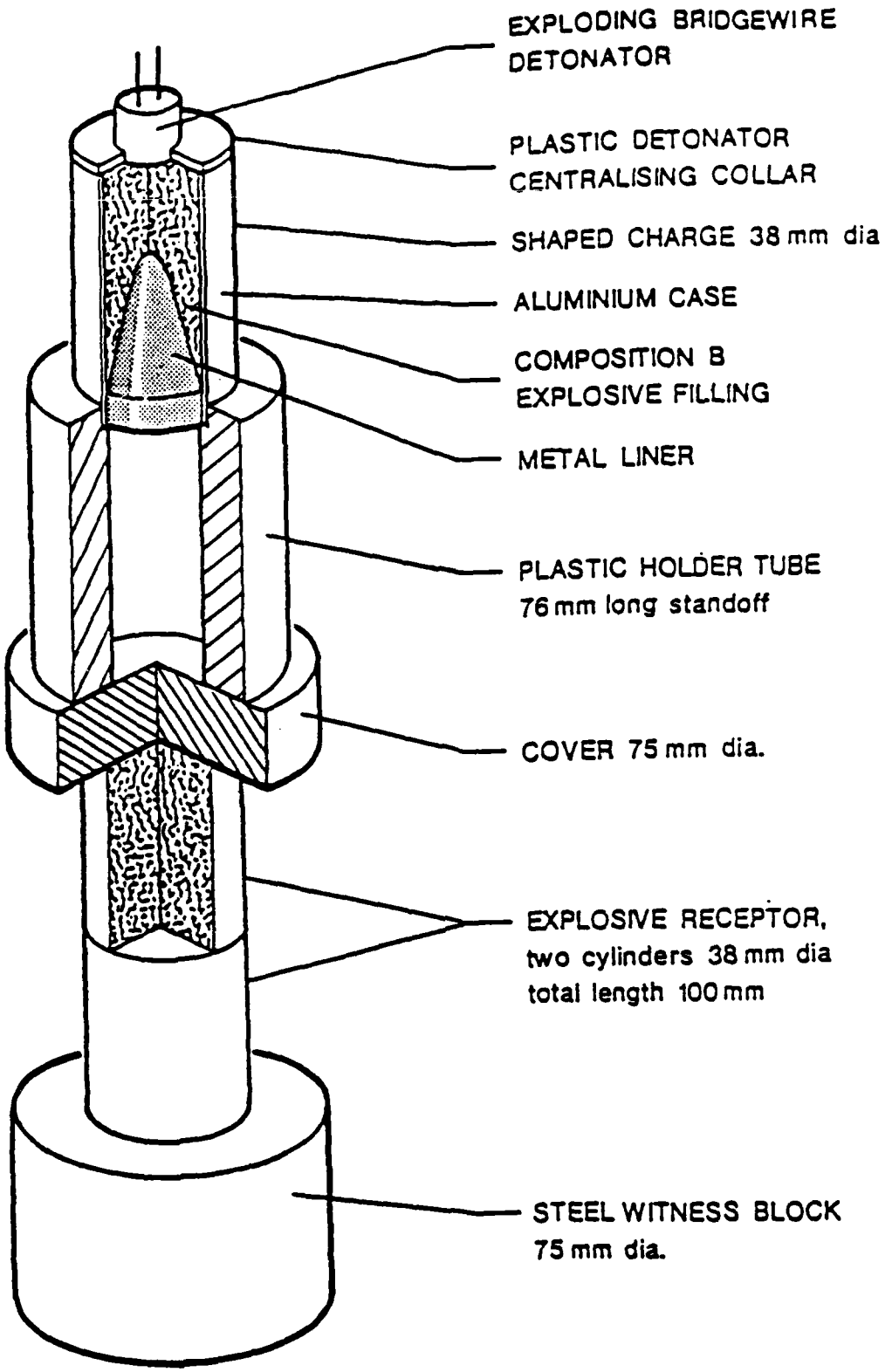


FIGURE 17 Assembly for the MRL Jet Sensitivity Test on Covered Explosives

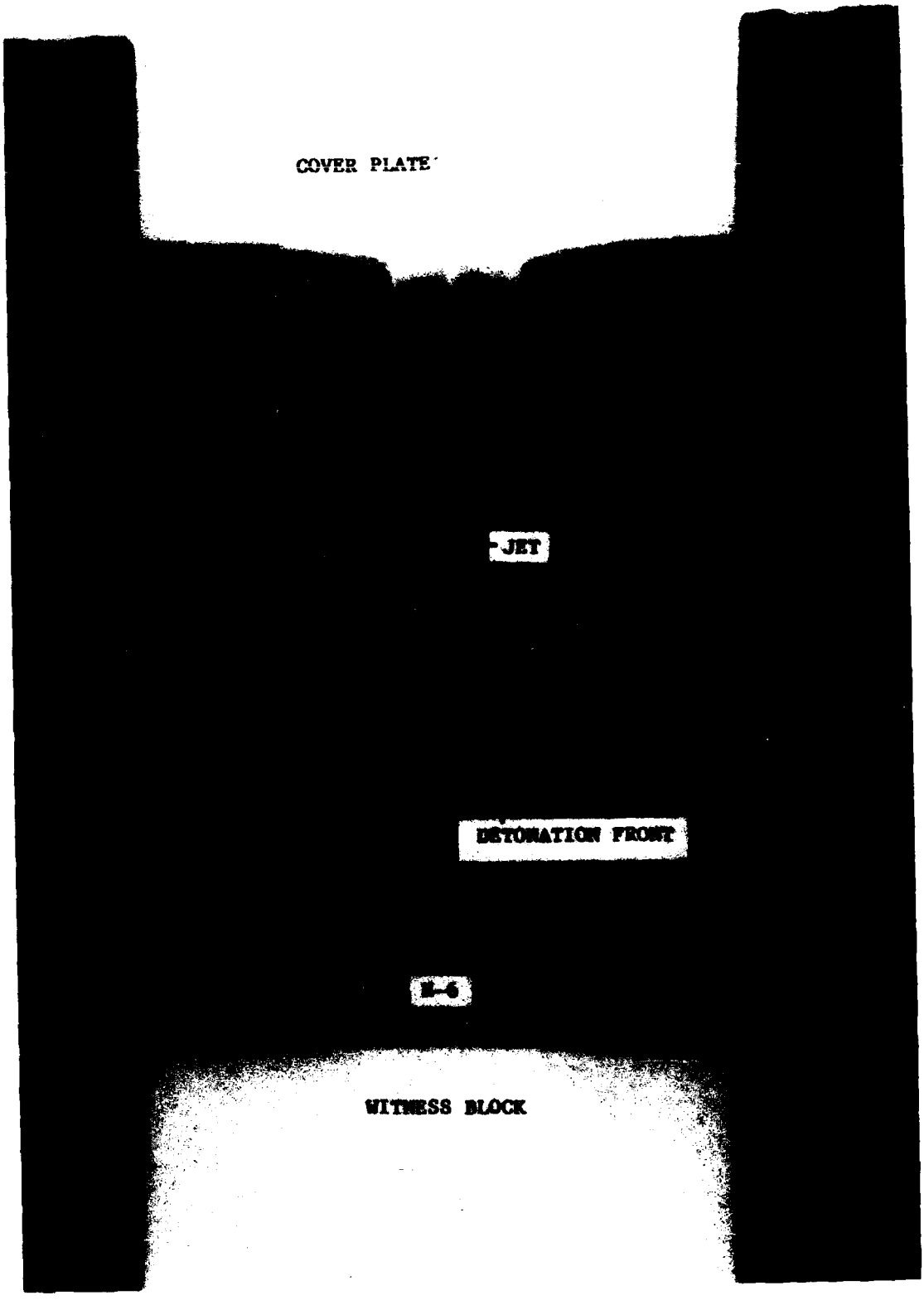


FIGURE 18 Flash radiograph of a jet initiating covered H-6

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COSATI GROUPS

ABSTRACT

The report describes an investigation to characterise the physical nature of cast H-6 and assess its stability and explosive properties. Scanning electron and optical microscopes were used to determine the aluminium and RDX distribution in the TNT matrix while explosive stability was assessed from the results of vacuum stability and temperature of ignition tests and differential scanning calorimetry. H-6 sensitivity was assessed from the results of the gap test, Rotter impact test, train test and jet sensitivity test. Some detonation parameters were determined experimentally and compared to BKW code estimates.

The study showed that Australian produced H-6 exhibited similar stability and sensitivity characteristics to Composition B and that the results supported data published for equivalent US tests. The aluminium was shown to be well distributed within the RDX/TNT system with only a small tendency to aggregate.