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# [illegible] Deflagration-to-Detonation Transition [illegible]N and HMX



Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Edited by Kyle Wheeler
Prepared by Janice E. Muir, Group M-7

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# The Deflagration-to-Detonation Transition in PETN and HMX

Robert H. Dinegar



Los Alamos National Laboratory
Los Alamos, New Mexico 87545

THE DEFLAGRATION-TO-DETONATION
TRANSITION IN PETN AND HMX

by

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ABSTRACT

The deflagration-to-detonation transition (DDT) can be made to occur in both PETN and HMX. The reaction is sensitive to the degree of subdivision and the compactness of the explosive in which the transition takes place. It apparently happens better with explosives of small specific surface loaded at low density.

Experiments using thin metal shims between the donor and transition-explosive charges suggest that transition-explosive compression makes an important contribution to the DDT process.

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## I. INTRODUCTION

Secondary explosives such as PETN,* HMX,** and RDX*** can be ignited by a hot wire at low current and low voltage. The threshold ignition levels as a function of explosive specific surface at several loading densities have been reported.[1] If the confinement of the ignited explosive is restrictive enough and other criteria are met, the deflagration will build up (transit) into a detonation. This reaction--the deflagration-to-detonation transition (DDT)--has been investigated by many in the past three or four decades. Recently we have reported some observations of the DDT reaction in PETN and HMX under a variety of assembly conditions.[1,2] This report includes the results of varying the

*Pentaerythritol tetranitrate ($C_5H_8N_4O_{12}$).

**1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane ($C_4H_8N_8O_8$).

***1,3,5,-trinitro-1,3,5,-triazacyclohexane ($C_3H_6N_6O_6$).

explosive specific surface and loading density in the transition zone as well as testing the confinement of the donor reaction.

## II. EXPERIMENTAL DETAILS

The test fixture was the ER-322 assembly, shown in Fig. 1. The bridgewire material is Nichrome V (80% nickel + 20% chromium) that is 0.05 mm in diameter and resistance-welded between Fe/Ni alloy electrodes 2.4 mm apart. The electrodes are embedded in a compressed-glass header. The donor explosive is loaded into a Lexan charge holder that is 4.4 mm in diameter and 4.0 mm long. The transition barrel is made in two sections; the sections are loaded separately and then screwed together to form the cylindrical cavity. This approach minimizes variation in the pressing density caused by loading and permits easy adjustment of the transition charge dimensions. Each section of the transition barrel has a 2.5-mm inner diameter and is 7.0 mm in length. The overall length of the barrel is 14 mm, which is significantly longer than the shortest explosive charge length found to undergo the DDT reaction.[2]

The specific surfaces ($S_o^P$) of the PETN and HMX differed. The $S_o^P$ value of the PETN† was varied by changing the rate of mixing water with PETN/acetone solutions. The HMX samples†† were the beta (β) polymorph material, which had been wet-ground to the desired fineness by 2.5-cm-diameter porcelain balls.

†Trojan Powder Company, 17 North 7th, Allentown, PA 18101.

††Holston Defense Corporation, P. O. Box 749, Kingsport, TN 37662.

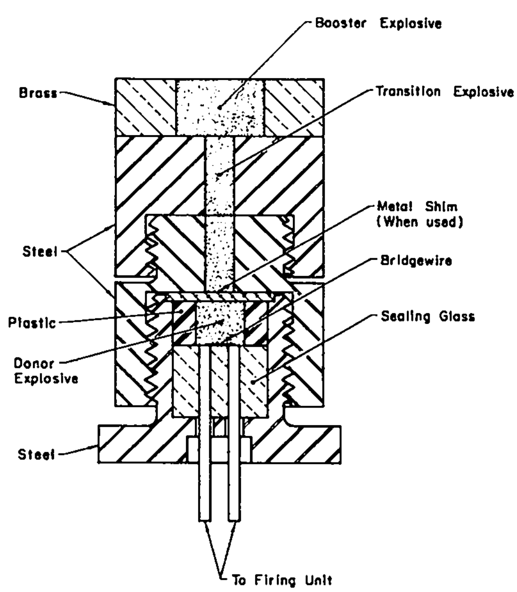


Fig. 1. DDT assembly (ER-322 Type).

The bridgewires were heated rapidly by passing direct current through the circuit from an external source. The voltage used was measured as 5 V; the current was approximately 4 A. The ignition-current threshold of PETN and HMX in these assemblies is less than 1 A.

## III. DISCUSSION OF RESULTS

### A. PETN

PETN of three widely differing specific surface values ($S_o^P$ = 3650, 8400, and 14,600 $cm^2/g$) at 1.0-$g/cm^3$ loading density was ignited. The DDT took place in each. Dents were produced in 6061-T6 aluminum witness slugs attached to the downstream end of the transition barrels. No consistent variation in dent depth with PETN specific surface change could be found. It appears, however, that the PETN with the smallest $S_o^P$ value (largest "average particle size") produced the deepest dent in the witness slug. Although the density of the PETN sample in the transition zone was varied between 1.0 and 1.4 $g/cm^3$, its specific surface was held constant at 3650 $cm^2/g$. Dents were again observed in the aluminum witness slugs, showing that the DDT reaction had occurred. Table I gives both sets of data.

TABLE I

DDT IN ALL-PETN ER-322 ASSEMBLIES WITHOUT A BOOSTER PELLET

Donor: PETN $S_o^P$ = 3650 $cm^2/g$ Density = 1.64 $g/cm^3$ Mass = 100 mg

| Transition Barrel | | | | | 6061-T6 Aluminum Witness Block Dent |
|---|---|---|---|---|---|
| PETN $S_o^P$ ($cm^2/g$) | Mass (mg) | Density ($g/cm^3$) | Diameter (mm) | Length (mm) | Depth (mm) |
| 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.7 |
| 8400 | 72 | 1.0 | 2.5 | 14.0 | 0.5 |
| 14600 | 72 | 1.0 | 2.5 | 14.0 | 0.5 |
| 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.4 |
| 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.8 |
| 3650 | 100 | 1.4 | 2.5 | 14.0 | 0.8 |

Booster pellets of PBX 9407* material (density = 1.6 g/cm$^3$) were substituted for the witness slugs to see whether the detonation produced in the DDT was strong enough to initiate a high-density secondary-explosive pellet. All systems detonated. The transition-zone PETN that was examined had an $S_o^P$ of 3650 cm$^2$/g and was pressed to 1.0-, 1.2-, and 1.4-g/cm$^3$ density. In these experiments we measured the diameter and the depth of the dent in a 2024 Dural witness block and calculated the estimated cylindrical volume. The data from these shots are given in Table II.

TABLE II

DDT IN ALL-PETN ER-322 ASSEMBLIES WITH A BOOSTER PELLET

Donor: PETN $S_o^P$ = 3650 cm$^2$/g Density = 1.64 g/cm$^3$ Mass = 100 mg

Booster Pellet: PBX 9407 Density = 1.6 g/cm$^3$ Mass = 376 mg

| Transition Barrel | | | | | 2024 Dural Witness Block Dent | | |
|---|---|---|---|---|---|---|---|
| PETN $S_o^P$ (cm$^2$/g) | Mass (mg) | Density (g/cm$^3$) | Diameter (mm) | Length (mm) | Depth (cm) | Diameter (cm) | Volume (cm$^3$) |
| 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.28 | 1.43 | 0.4 |
| 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.23 | 1.41 | 0.4 |
| 3650 | 100 | 1.4 | 2.5 | 14.0 | 0.21 | 1.54 | 0.4 |

From the earliest days in hot-wire initiation work, it has been recognized that confinement is crucial.[1,3] In these systems the downstream end of the donor is only partially confined by metal. Placing a thin metal shim between the donor and transition charge would increase the confinement of the donor reaction, but we didn't know whether this would interfere with, enhance, or show no effect on the behavior of the transition charge. To study this we chose aluminum (6061-T6) and stainless steel (303) shims of various thicknesses. Table III shows the thicknesses of the thin shims that work in all-PETN DDT detonators--0.025- to 0.100-mm aluminum as well as 0.025- and 0.50-mm stainless steel. The shims appear to enhance the transition--at least they do not interfere. This leads us to postulate that their action (1) provides higher pressure through better and longer confinement of the deflagration in the donor and (2) more efficiently compresses the transition explosive in which the DDT reaction takes place.

*94 wt% RDX + 6 wt% EXON 461.

TABLE III

THE EFFECT OF SHIMS ON DDT IN ALL-PETN ER-322 ASSEMBLIES

Donor: PETN $S_o^P$ = 3650 $cm^2/g$ Density = 1.64 $g/cm^3$ Mass = 100 mg
Booster Pellet: PETN Density 1.3 $g/cm^3$ Mass = 306 mg

| End-Closing Shim Type/Thickness (mm) | Transition Barrel PETN $S_o^P$ ($cm^2/g$) | Mass (mg) | Density ($g/cm^3$) | Diameter (mm) | Length (mm) | 2024 Dural Witness Block Dent Depth (cm) | Diameter (cm) | Volume ($cm^3$) |
|---|---|---|---|---|---|---|---|---|
| 6061-T6 Aluminum | | | | | | | | |
| 0.025 | 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.24 | 1.22 | 0.3 |
| 0.050 | 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.20 | 1.09 | 0.2 |
| 0.100 | 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.21 | 1.22 | 0.2 |
| 303 Stainless Steel | | | | | | | | |
| 0.025 | 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.22 | 1.19 | 0.2 |
| 6061-T6 Aluminum | | | | | | | | |
| 0.025 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.23 | 1.22 | 0.3 |
| 0.050 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.24 | 1.11 | 0.2 |
| 0.075 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.18 | 1.25 | 0.2 |
| 0.100 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.19 | 1.19 | 0.2 |
| 303 Stainless Steel | | | | | | | | |
| 0.025 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.20 | 1.25 | 0.3 |
| 0.050 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.19 | 1.25 | 0.2 |

There seems to be an upper limit of PETN density (about 1.4 $g/cm^3$) that will undergo the DDT reaction. A density of 1.6 $g/cm^3$ consistently fails to give evidence of detonation.[1,3] Even though the great majority of these failures were observed in systems without donor end-closing shims, no improvement was noted when the metal shim was inserted in a few experiments. Apparently there is a maximum density that will transit to detonation; this is consistent with the DDT mechanism proposed by Sulimov, one aspect of which is that combustion products penetrate through pores into unreacted explosive, preheating the material and helping initiate a low-velocity detonation.[4] It is also consistent with the mechanism put forth by Campbell[5] that adiabatic shear occurring within the crystallites is important, it not determinative. Although the difficulty in obtaining a high degree of dent reproducibility precludes our being certain, an apparent preference of the DDT reaction for that PETN sample having the smallest $S_o^P$ number also agrees with these proposals.

The donor density can be decreased to 1.44 $g/cm^3$ and/or the PETN booster pellet can be replaced by the more standard high-density (1.6-$g/cm^3$) PBX 9407 explosive, and the assemblies will function properly. The dent in the witness block is invariant if the donor density is decreased but increases if the high-density PBX 9407 explosive is used.

HMX can be substituted for PETN in the transition zone of DDT assemblies, but the powder and mechanical prerequisites for the deflagration to build up into a detonation are much stricter. We have found that those transition charges that do build up require (1) HMX powder with both a relatively low $S_o^P$ value (3450 $cm^2/g$) and loading density (1.0 $g/cm^3$ or less) as well as (2) the thinnest of donor-confining aluminum shims. These requirements appear to reflect several properties of HMX as compared with PETN: HMX has a lower shock sensitivity, porosity, and particle-size effect. The data from the experiments carried out in these areas are given in Table IV.

TABLE IV

ADDITIONAL DATA USING PETN AS DONOR EXPLOSIVE IN ER-322 ASSEMBLIES WITH BOOSTER PELLETS

Donor: PETN $S_o^P$ = 3650 $cm^2/g$ Density = 1.44 $g/cm^3$ Mass = 88 mg
Booster Pellet: PETN Density = 1.3 $g/cm^3$ Mass = 306 mg

| End-Closing Shim Type/Thickness (mm) | Transition Barrel | | | | | 2024 Dural Witness Block Dent | | |
|---|---|---|---|---|---|---|---|---|
| | PETN $S_o^P$ ($cm^2/g$) | Mass (mg) | Density ($g/cm^3$) | Diameter (mm) | Length (mm) | Depth (cm) | Diameter (cm) | Volume ($cm^3$) |
| 6061-T6 Aluminum | | | | | | | | |
| 0.025 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.18 | 1.21 | 0.2 |
| 0.100 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.20 | 1.19 | 0.2 |
| 303 Stainless Steel | | | | | | | | |
| 0.025 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.23 | 1.06 | 0.2 |
| 0.050 | 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.22 | 1.10 | 0.2 |

Donor: PETN $S_o^P$ = 3650 $cm^2/g$ Density = 1.64 $g/cm^3$ Mass = 100 mg
Booster Pellet: PBX 9407 Density = 1.6 $g/cm^3$ Mass = 376 mg

| End-Closing Shim Type/Thickness (mm) | Transition Barrel | | | | | 2024 Dural Witness Block Dent | | |
|---|---|---|---|---|---|---|---|---|
| | Explosive $S_o^P$ ($cm^2/g$) | Mass (mg) | Density ($g/cm^3$) | Diameter (mm) | Length (mm) | Depth (cm) | Diameter (cm) | Volume ($cm^3$) |
| 6061-T6 Aluminum | | | | | | | | |
| 0.025 | PETN: 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.26 | 1.34 | 0.4 |
| 0.050 | PETN: 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.24 | 1.34 | 0.3 |
| 0.100 | PETN: 3650 | 86 | 1.2 | 2.5 | 14.0 | 0.24 | 1.33 | 0.3 |
| 0.025 | HMX: 3450 | 72 | 1.0 | 2.5 | 14.0 | 0.25 | 1.31 | 0.3 |
| 0.100 | HMX: 3450 | 72 | 1.0 | 2.5 | 14.0 | | No Dent | |

B. HMX

All-HMX hot-wire DDT detonators can be assembled successfully. Again, conditions are more restrictive than in all-PETN systems, apparently because of the less sensitive nature of HMX explosives. The effect of particle size and loading density on the ignition process is visible using HMX as the donor charge, whereas it is relatively unimportant with PETN.[1] Increasing both pressing density and $S_o^P$ value (decreasing "average particle size") permits ignition of HMX using lower firing voltages and currents.

HMX whose $S_o^P$ number was 8300 $cm^2/g$ was chosen as the donor charge. The pressing density usually was 1.64 $g/cm^3$. The electrical firing conditions of 5-10 V (4-8 A) were well above the 50% fire/fail values, nominally 1 V/1 A. The downstream end of the donor was confined by 6061-T6 aluminum or 303 stainless steel shims.

In the transition zone, the loading densities tried were 0.8 and 1.0 $g/cm^3$. More compact pressings were eliminated because previous work done in SE-1-N assemblies indicated these would not be initiated.[1] Lower pressing densities of HMX do not hold together. The relatively coarse ($S_o^P$ = 3450 $cm^2/g$) sample of HMX was used because the flying plate mode of transition-charge initiation to detonation indicated that 8300-$cm^2/g$ material would not initiate a high-density PBX 9407 pellet.

The results are given in Table V. With an HMX transition-charge loading density of 1.0 $g/cm^3$, none of the detonators that ignited produced a dent in a 2024 Dural witness block. A larger diameter transition zone did not help. When PETN was substituted for HMX in the transition zone at 1.0 $g/cm^3$ density, a DDT reaction occurred. The use of PETN as a donor charge gave a dent, evidence that a DDT reaction can be obtained in HMX at a density of 1.0 $g/cm^3$, but not with an HMX donor. The successful all-HMX combinations occurred only at a density of 0.8 $g/cm^3$ without a shim or with 6061-T6 aluminum or 303 stainless steel shims 0.025 mm thick. Thicker shims were not compatible with achievement of a DDT reaction.

TABLE V

EFFECT OF SHIMS ON DDT IN ALL-HMX ER-322 ASSEMBLIES WITH BOOSTER PELLETS

Donor: HMX $S_o^P$ = 8300 cm²/g Density = 1.64 g/cm³ Mass = 100 mg
Booster Pellet: PBX 9407 Density = 1.6 g/cm³ Mass = 376 mg

| End-Closing Shim Type/Thickness (mm) | Explosive $S_o^P$(cm²/g) | Transition Barrel Mass (mg) | Density (g/cm³) | Diameter (mm) | Length (mm) | 2024 Dural Witness Block Dent Depth (cm) | Diameter (cm) | Volume (cm³) |
|---|---|---|---|---|---|---|---|---|
| 6061-T6 Aluminum | | | | | | | | |
| None | HMX: 3450 | 58 | 0.8 | 2.5 | 14.0 | 0.21 | --- | --- |
| 0.025 | HMX: 3450 | 58 | 0.8 | 2.5 | 14.0 | 0.20 | 1.46 | 0.3 |
| 0.050 | HMX: 3450 | 58 | 0.8 | 2.5 | 14.0 | | No Dent | |
| 0.100 | HMX: 3450 | 58 | 0.8 | 2.5 | 14.0 | | No Dent | |
| None | HMX: 3450 | 186 | 1.0 | 4.0 | 14.0 | | No Dent | |
| 0.025 | HMX: 3450 | 186 | 1.0 | 4.0 | 14.0 | | No Dent | |
| 0.025 | HMX: 3450 | 72 | 1.0 | 2.5 | 14.0 | | No Dent | |
| 0.050 | HMX: 3450 | 72 | 1.0 | 2.5 | 14.0 | | No Dent | |
| 0.100 | HMX: 3450 | 72 | 1.0 | 2.5 | 14.0 | | No Dent | |
| 0.050 | PETN: 3650 | 72 | 1.0 | 2.5 | 14.0 | 0.25 | 1.30 | 0.3 |
| 303 Stainless Steel | | | | | | | | |
| 0.025 | HMX: 3450 | 58 | 0.8 | 2.5 | 14.0 | 0.23 | 1.33 | 0.3 |
| 0.125 | HMX: 3450 | 58 | 0.8 | 2.5 | 14.0 | | No Dent | |
| 0.025 | HMX: 3450 | 72 | 1.0 | 2.5 | 14.0 | | No Dent | |

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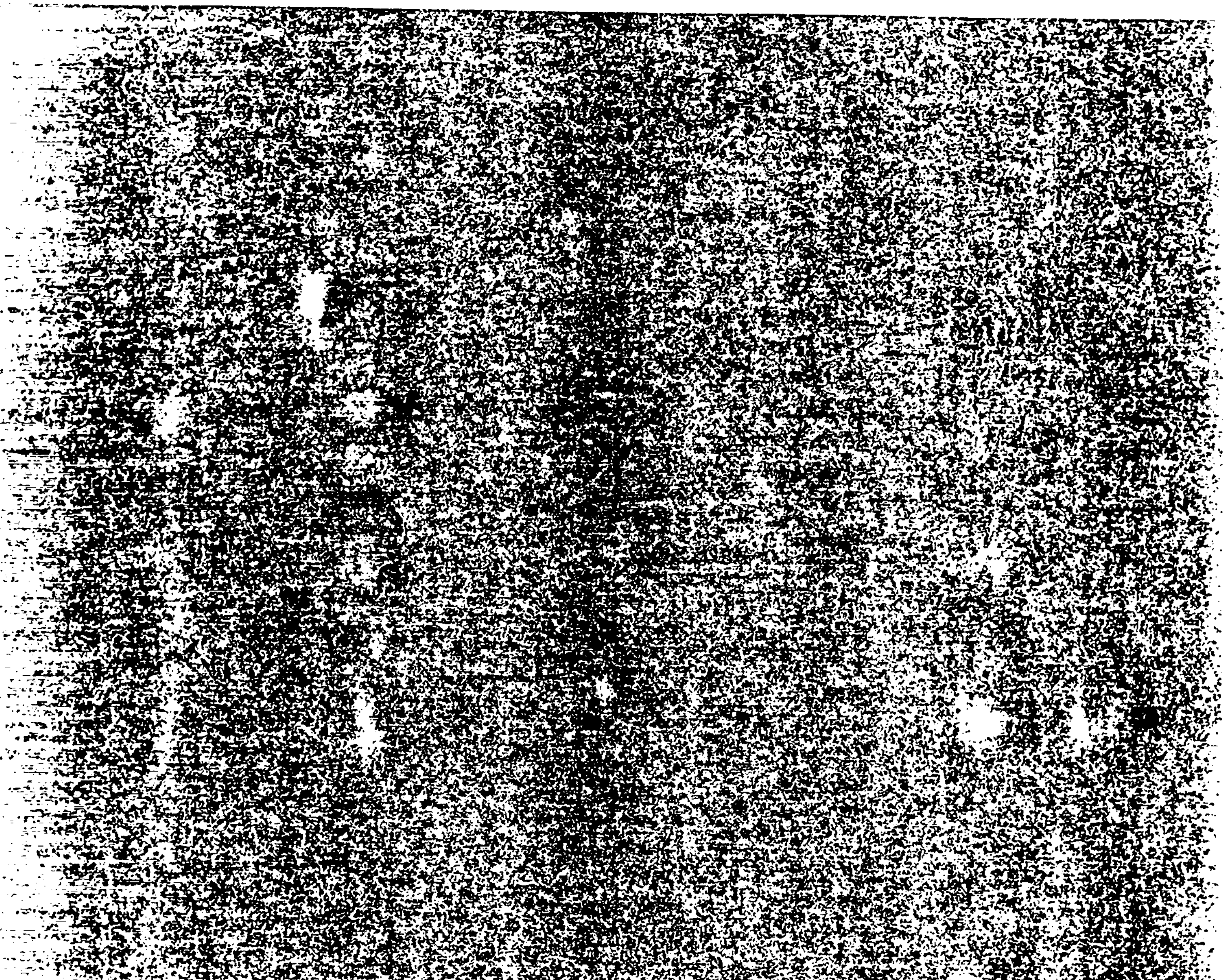

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