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AWRE REPORT No. T 30/63

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VIXEN A Trials 1959

Experiments with Weapon Type Assemblies: Destruction of Red Beard Mk. 1 by Fire

K. Stewart

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K. Stewart

Summary

In the destruction of a Red Beard Mk. 1 type weapon by fire the combustion of the H.E. may be complete, or nearly so, before the tamper and core temperatures rise appreciably above ambient. This result suggests that it should be possible to prevent the spread of plutonium contamination by attacking the fire as soon as the H.E. has burnt out.

W11(RED BEARD)
W52(VIXEN A):665.5
W:614.84

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1. INTRODUCTION

The object of these tests was to study the behaviour of a Red Beard warhead during its destruction by fire. It had already been demonstrated that the high explosive was more likely to burn than to detonate but no information was available on the mode of ignition and combustion of the tamper and nuclear assembly.

As one of the consequences of such an accident could be the release of plutonium oxide in particulate form, measurements were made of the amount and distribution of material dispersed downwind. The fine particulate material, which would reach the lungs if inhaled, was of primary interest.

The experimental procedures employed in the determination of the distribution of particulate material have been described in an earlier report [1].

2. THE MODIFIED RED BEARD ASSEMBLIES

The experimental assemblies employed to represent Red Beard Mk. 1 warheads differed from the Service warhead in the following ways:-

(a) In the nuclear assembly the fissile material was replaced by natural uranium and the neutron initiator was omitted.

(b) The nuclear assembly and associated loading mechanism was modified to permit the introduction of platinum-rhodium thermocouples (see Figure 1).

(c) The assembly and the associated strong ring were mounted on a metal stand and were not enclosed in a weapon case (see Figure 4).

3. DETAIL OF THE EXPERIMENTS

As noted earlier the experimental procedures used to sample the airborne and deposited material downwind of the event have been described in an earlier report [1]. The experimental layouts of sampling devices were very similar to those used for the other experiments in this series and are shown for one of the experiments in Figure 12. The analytical methods are discussed in the two other reports on the Vixen A 1959 series [1, 2]. The meteorological conditions selected were those corresponding to zero temperature gradient (or average conditions) with wind speeds less than 15 m.p.h.

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The replica weapon assembly was supported on a stand in a 7 ft square tray which was 4 in. deep so that the lowest lens was a few inches above the level of the fuel on the tray (Figure 6). A total of 140 gal of AVGAS fuel was used and this was fired by an igniter. A sound record was made of the experiment in order to obtain an indication of the times when the high explosive ignited or when explosion occurred. This record was supplementary to colour cine records, in which it was thought the flame and smoke from the fire might occasionally preclude a clear picture being obtained. The sound tape recorder and the recorder for the thermocouples were contained in a 3 ft steel cube buried some 8 ft to the windward of the tray. The cameras were placed upwind of the fire in an 8 ft steel cube with optically flat windows.

4. EXPERIMENTAL RESULTS

Both experiments followed similar courses. Ignition at a lens started after about 2 min heating and progressed to ignition of the supercharge at 5 - 8 min. The H.E. was completely consumed in about 12 min. The magnesium strong ring was ignited by the burning H.E. and continued to burn after both the H.E. and fuel had burnt out. The uranium core and tamper were completely oxidised but this reaction took many hours. In the second experiment the core smouldered for two days and was finally extinguished with sand. The steel lens structure in general survived the fire and served to contain the remnants of the uranium components. The temperature versus time records are shown in Figures 2 and 3 and photographs of the experimental assemblies before, during and after the experiments are given in Figures 4 to 9. The times of ignition of the first lens, of the supercharge and completion of combustion of the H.E. which are given in Figures 2 and 3 were obtained by analysis of the temperature, film and sound records. It is noteworthy that the temperatures of core and tamper in both experiments did not exceed 750°C but once the metal ignited its temperature remained in the region of 500°C for more than 1 h (the maximum running time of the recording galvanometer was 72 min). Subsequent examination showed that the oxidation reaction proceeded steadily to completion.

Fortunately, the two experiments although very similar did differ in one significant way. In the first experiment the replica loading bar which carried the core and the thermocouple leads had not been displaced by the end of the experiment. Hence the spherical shell of the tamper was probably still complete at the time the H.E. finally burnt out. The temperatures of core and tamper at this time were somewhat less than 100°C and the temperature of about 600°C was only reached some 6 min later. The combustion of the magnesium strong ring which was in progress during this period (see Figure 6) probably ensured the

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ignition of the uranium. In the second experiment the replica loading bar apparently collapsed into the tamper shell during the combustion of the supercharge and the uranium was ignited earlier (see Figures 5 and 9). About the time when the supercharge ignited, the lens structure was broken underneath (see Figure 9) and the whole assembly was jolted severely. It was at this time that the replica loading bar probably broke loose. The early rise in the temperature of both core and tamper suggests that hot gases and perhaps flames, entered the interior of the assembly.

The results of the analysis of the samples collected on the sampling array during these experiments are given in Tables 1 - 4. The cascade impactors were switched off within 2 h from the start of each experiment but the deposition samples were not collected until the next day. Therefore, the impactor results indicate the level of hazard downwind during the course of the fire and for some time afterwards, whereas the deposition results possibly represent dispersal of uranium oxide over a longer period. However, earlier experience with slowly burning uranium in the open suggests that the amount dispersed would have been small and would only affect the close in part of the array. The heat liberated during the combustion of the H.E. caused a rapid evaporation of fuel which burnt to give a black voluminous cloud. The fuel was burnt out by about the same time as the H.E. finished burning. In the first experiment the smoke cloud produced during the combustion of the fuel (similar to that shown in Figure 5) was observed to have risen to about 1 000 ft at 1 000 - 1500 yd downwind. The white cloud produced subsequently, which contained the products of the combustion of residual H.E. and magnesium, aluminium and uranium, was less readily observed (see Figure 6) but did not appear to rise to the same extent, presumably because of the smaller rate of heat release. A similar sequence of events occurred on the second experiment in which the combustion of uranium is known to have been established whilst the fuel and H.E. were still burning. The cascade impactor results for the two experiments are similar, there being no significant change over the entire range of measurement which was from 200 yd to about 2600 yd. The average total impactor samples varied from 0.53 μg at 200 yd to about 0.14 μg at 2000 yd in the first experiment and showed a smaller variation in the second one (see Tables 1 and 2). Such distributions would not be unexpected from sources of this kind because the fine particulate could be dispersed approximately uniformly both laterally and with height to several hundred feet at about ¼ mile downwind [1]. The dependence of deposition level with range was rather different for the two rounds. In the case of the first experiment, in which the uranium still remained intact during the combustion of the H.E., a marked peak in the average contamination levels is observed in the region of 200 - 1 000 yd downwind. Whereas in the case of the second experiment in

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which the uranium was ignited during the combustion of the H.E. the contamination out to about 100 yd was much heavier but decreased steadily with increasing range.

4.1 Meteorological Information

The detailed meteorological information collected during the periods of these experiments is summarised in Table 5. These measurements were made at a special site about 2000 yd to the south of the firing area. In general the weather obtained corresponded quite well to zero temperature gradient or average conditions. These occurred as was expected during late afternoon and this period of the day was selected because of final preparations on the sampling array, rather than early morning when the stability of the atmosphere would be similar. Of the two periods, the afternoon one is probably the less attractive because the change is from unstable to the stable conditions which exist at night.

5. DISCUSSION

The two replica Red Beard warhead assemblies burnt without explosion occurring; a result which has been observed in a number of other similar trials. To date the H.E. has not detonated in these circumstances, so that it appears the risk of explosion from a Red Beard warhead involved in a fire is small.

The maximum temperatures observed in the core and tamper were about 700°C but the petrol fire was finished by the time the supercharge had burnt out. If the fuel fire were not finished by the time the explosive had burnt away, as might be the case in an accident, the metal temperature would be greater. However, the metal temperature did not rise appreciably until the explosive fire was well advanced or finished which means that, provided the main fire can be extinguished soon afterwards, the combustion of the metal can be prevented or at least limited in extent. The temperature reached (viz 700°C) would be sufficient to melt and ignite plutonium but the core is contained within a gold sheath and a uranium shell so that there appears to be a good chance that the dispersal of plutonium could be prevented entirely.

The small change in the cascade impactor samples with range downwind (and across wind) is evidence of the buoyant nature of the plume from the fire during both the fuel and H.E. burning stage immediately after this while the magnesium strong ring, aluminium and uranium were burning. The mean value of all impactor samples out to range of 1½ miles downwind was 0.35 μg of which about 75% was in the hazardous size range from the aspect of inhalation (see Figure 10). The inhalation

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of this amount of natural uranium would result in a dose of about 0.01 mrem to the lungs. If the material were plutonium, the dose from this amount would be about 3 rem but this seems unlikely to occur because of the degree of containment. It should be noted that even when exposed and burnt to oxide, the amount of plutonium dispersed would be expected to be only about 1/5 of the amount of uranium under similar circumstances [1].

The marked difference between the two deposition patterns which is shown by the average crosswind levels versus range in Figure 11 is not properly understood but may be accounted for to some extent by the different courses the two experiments followed coupled with the fact that an alloy of uranium containing about 20% aluminium has been found to ignite readily in air, whereas one containing 80% aluminium is inert [3]. In the first experiment as the supercharge burnt away (and presumably the upper surface of the tamper would be exposed first as melted explosive would flow to the bottom) the aluminium cladding would be melted and burnt off too. Subsequently, the uranium surface would be exposed and oxidation would set in. The surface might be alloyed with a little residual aluminium which would ensure ignition. This sequence of events is in accord with the temperature versus time records, which show that the temperature of the tamper reached about 600°C some 6 min after the bulk of the supercharge had burnt away. In the second experiment the tamper temperature reached the 600°C region whilst the supercharge was still burning which may have led to the formation of an alloy layer rich in aluminium on the surface of the uranium tamper and this would reduce the amount of oxide released.

The amounts of uranium deposited out to about 3000 yd downwind were about 650 and 50 g for the first and second experiments, respectively. These amounts are very small fractions of the total amount of uranium present in each replica warhead (17 kg). The fallout contours for the first experiment are shown in Figure 12. The overall particle size distributions for the two experiments appear to have been markedly different because whereas the average cascade impactor sample (0.42 μg) from the first was only about 50% greater than that from the second (0.28 μg), the amounts deposited were in the ratio of 13:1.

6. CONCLUSIONS

When a Red Beard warhead is destroyed by burning in a fire the explosive may be completely burnt before the metal of the core and tamper is ignited. Even if these metal components were ignited before the combustion of the explosive was complete, the temperatures reached would probably be only in the region of 700°C. The plutonium in the nuclear assembly is contained within gold and uranium sheaths which

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would probably prevent its dispersion completely, provided the fire was extinguished soon after the H.E. had burnt out.

If the combustion of the warhead were to go to completion, it is reasonable to conclude from the results of these experiments and those with bare uranium and plutonium [1] that less than 1% of the plutonium would be released in particulate form.

In the case of a sealed pit type warhead it is probable that an outer sheath of beryllium around the fissile material would prevent the release of plutonium and uranium completely if the fire were brought under control soon after the combustion of the H.E. was complete. Aluminium cannot, because of its lower melting point, provide the same degree of protection.

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TABLE 1

Cascade Impactor Samples, μμc: 1st Experiment

Sampling Station		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mean	Standard Error of Mean	Average Range, yd
Nominal Range, yd	Impactor Stage																																		
	1	0.292	18.120*	0.059	0.965	0.205	4.930*	0	0.059	0	0	0.380	0.205	0.117	0	0	0.088	0.526	0.029	0.088	0.059	0.088	0.085	0.067	0.076	0.067							0.150		
	2	0.278	0.614	0.307	0.417	0.307	0	0.139	0.111	0.056	0	0.250	0.307	0.223	0.028	0.139	0.223	0.808	0.500	0.111	0.223	0.250	0	0	0.006	0.017							0.204		
200	3	0.085	0	0.081	0	0.113	0	0.029	0	0.169	0.029	0.480	0.113	0.056	0.056	0.085	0.056	0.141	0.169	0.226	0.198	0.029	0.067	0.065	0	0.174							0.105		
	4	0	0.027	0.054	0.135	0.054	0.081	0	0	0.081	0.162	0.030	0	0.024	0.042	0.015	0.117	0.057	0.092	0.014	0	0.140	0.040	0.025	0	0.074							0.050		
	5	0.016	0	0	0.030	0.034	0	0	0	0	0	0.006	0	0	0	0	0	0.116	0.017	0.064	0.028	0	0.029	0	0.009	0.013							0.016		
	TOTAL	0.671	18.761	0.501	1.547	0.713	5.011*	0.168	0.170	0.306	0.191	1.146	0.625	0.420	0.126	0.239	0.484	1.648	0.807	0.503	0.508	0.507	0.221	0.157	0.091	0.345							0.526	0.084	210
	1	0.086	0.172	0	0.029	0.086	0	0	0.057	0.029	0.201	0.430	0.258	0.057	0.029	0.086	0.057	0	0.086	0.115	0.029											0.090		
	2	0	0.057	0.038	0	0	0.032	0.060	0.026	0.035	0	0.038	0	0.107	0.020	0	0.038	0.048	0.027	0.011	0.059											0.029		
500	3	0.140	0.197	0.056	0.197	0.084	0.084	0.029	0.140	0.113	0.197	0.534	0.140	0.113	0.113	0.056	0.113	0.113	0.056	0.226	0.282											0.149		
	4	0.226	0.056	0.056	0.056	0.056	0.226	0.113	0.168	0.140	0.084	0.030	0	0.060	0	0	0	0.090	0	0.090	0											0.073		
	5	0	0.042	0.040	0.083	0.062	0	0.073	0.054	0.045	0.006	0.080	0.039	0.067	0.086	0.041	0	0.038	0	0	0.067											0.041		
	TOTAL	0.452	0.524	0.190	0.365	0.288	0.342	0.265	0.445	0.362	0.488	1.112	0.437	0.404	0.248	0.183	0.208	0.289	0.169	0.442	0.437											0.383	0.045	480
	1	0.086	0	0.030	0	0.049	0.020	0	0	0.026	0	0.024	0.027	0	0.028	0.035	0.110	0															0.026		
	2	0	0.117	0.029	0.059	0.175	0.029	0	0.146	0	0.029	0.175	0.059	0	0	0.059	0	0.029															0.053		
1000	3	0	0	0.087	0	0	0	0	0.262	0	0.029	0.122	0.087	0.117	0	0.059	0.029	0.029															0.048		
	4	0	0.023	0.029	0	0	0	0	0.060	0	0.090	0	0	0.180	0	0.016	0.021	0.021															0.026		
	5	0.046	0	0	0	0.028	0	0	0	0.008	0	0	0	0.008	0	0	0.032	N/S															0.007		
	TOTAL	0.132	0.140	0.175	0.059	0.252	0.049	0	0.468	0.034	0.148	0.321	0.173	0.305	0.028	0.169	0.192	0.079															0.160	0.030	1110
	1	0.102	0	0.066	0	0.008	0.053	0	0	0	0	0.153	0	0.081	0	0	0	0.080	0.210	0.233	0.138	0.245	0.214	0.220	0.158	0.158	0.041	0.047	0	0.059	0.102	0.039	0.078		
	2	0.061	0	0.023	0	0.072	0.033	0	0	0	0.039	0.093	0	0.059	0	0	0	0.096	0.065	0.119	0.059	0	0.047	0	0.019	0.062	0.062	0.117	0.065	0.158	0.034	0	0.041		
1500	3	0.054	0.027	0	0	0.081	0	0	0.081	0	0.108	0	0	0.108	0.081	0	0	0.028	0.021	0	0	0	0.144	0.116	0.016	0.058	0.173	0	0.058	0.058	0.173	0.231	0.055		
	4	0	0.081	0.081	0	0	0	0	0	0	0.054	0	0.189	0	0	0.027	0	0	0	0.103	0.006	0.045	0	0.007	0.114	0.107	0.013	0.086	0.116	0.086	0.029	0	0.037		
	5	0	0	0	0.008	0.051	0	0.040	0	0	0	0	0	0	0.008	0.008	0	0.032	0	0	0.006	0.004	0.116	0.045	0.126	0.156	0.208	0.092	0.114	0.044	0.444	N/S	0.048		
	TOTAL	0.176	0.108	0.127	0.008	0.276	0.066	0.040	0.081	0	0.201	0.246	0.189	0.248	0.089	0.035	0	0.236	0.296	0.455	0.209	0.294	0.521	0.388	0.533	0.541	0.497	0.342	0.353	0.405	0.782	0.270	0.260	0.034	1700
	1	0.057	0	0.029	0.086	0	N/S	0	0	0	0	0	0	0	0	0	0	0	0	0.029	0	0											0.010		
	2	0.143	0	0	N/S	0	N/S	0.081	0.108	0	0.352	0.054	0.054	0	0	0	0	0	0	0	0.162	0.108											0.053		
2000	3	0	0.028	0.056	0.028	0.111	N/S	0	0.084	0	0	0	0	0	0.056	0	0	0.028	0.028	0	0	0											0.021		
	4	0	0	0	0.029	0.200	N/S	0.057	0.086	0.086	0.086	0	0	0	0	0	0.029	0	0	0.057	0.086	0											0.036		
	5	0	0	0.035	0.074	0	N/S	0	0	0	0	0.008	0	0	0.054	0.009	0.008	0	0.250	0.010	0	0											0.022		
	TOTAL	0.200	0.028	0.120	0.217	0.311	-	0.138	0.278	0.086	0.438	0.062	0.054	0	0.110	0.009	0.037	0.028	0.278	0.096	0.248	0.108											0.142	0.027	2380

Results Obtained at Heights above 5 ft at 500 yd Range

Station 9 30 ft	Station 13 30 ft	Station 11 250 ft	Station 15 200 ft	Station 15 300 ft
0.105	0.053	0.118	0.026	0
0.053	0.026	0.071	0.026	0.034
0	0	0.118	0.026	0.056
0.053	0.053	0.071	0	0.028
0.036	0.013	0	0.096	0.011
0.247	0.145	0.378	0.174	0.129

Results marked * not included in average.

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2. "Vixen A Trials 1959: Experiments with Implosion Assemblies: Dispersal of Beryllium and Uranium". AWRE Report No. T27/63

3. Dr. J. E. Antill, AERE: private communication

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TABLE 2

Cascade Impactor Samples, μμc: 2nd Experiment

Sampling Station		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Mean	Standard Error of Mean	Average Range, yd
Nominal Range, yd	Impactor Stage																												
	1	0.054	0.115	0.005	0.010	0	0	0	0.117	0	0.035	0.070	0	0	0.041	0	0	0.056	0.139	0.028	0.056	0.084	0.278	0.084	0.028	0.111			
	2	0.084	0.084	0.056	0.028	0	0.139	0	0	0	0.056	0.047	0.091	0	0.006	0.006	0	0.006	0	0.046	0.028	0.084	0.139	0.167	0.028	0			
200	3	0.029	0.088	0.147	0	0	0.088	0.234	0	0.205	0.205	0.176	0.117	0	0	0	0.147	0.176	0.088	0.088	0	0.006	0	0	0.018	0.055			
	4	0	0.028	0	0	0.017	0	0	0	0	0	0	0.017	0	0	0	0	0.008	0.148	0.014	0	0	0	0	0.004	0			
	5	0	0	0.060	0.083	0	0.047	0.107	0	0	0	0	0.051	0	0.041	0.008	0	0	0.062	0	0	0	0	0	0.054	0.014			
	TOTAL	0.167	0.315	0.268	0.121	0.017	0.274	0.341	0.117	0.205	0.296	0.293	0.276	0	0.088	0.014	0.147	0.246	0.437	0.176	0.084	0.174	0.417	0.251	0.132	0.180	0.201	0.024	210
	1	0	0	0.035	0	0.077	0	0	0.026	0	0	0	0.127	0	0.078	0	0.078	0.014	0	N/S	0.023								
	2	0.019	0.109	0.077	0	0	0.019	0	0.080	0	0.034	0	0.017	0.017	0.044	0.040	0.174	0.055	0	0.029	0								
	3	0.084	0.140	0.029	0	0.112	0.084	0.084	0.056	0	0.112	0.063	0.041	0.117	0.100	0.015	0.096	0.112	0.111	0.056	0.112								
	4	0	0	0.059	0	0.083	0.056	0	0.102	0	0	0	0	0.022	0.017	0.019	0.075	0	0	0	0								
	5	0.030	0.002	0	0.102	0	0.022	0	0.080	0	0	0	0	0	0.122	0	0.071	0.028	0	0.022	0								
	TOTAL	0.133	0.251	0.200	0.102	0.272	0.181	0.084	0.344	0	0.146	0.063	0.185	0.156	0.361	0.074	0.494	0.209	0.111	0.107	0.135								
	1	0.141	0	0	0.126	0.044	0						0	0.024	0	0.142	0.119	0.045	0	0.023	0.090	0.067							
	2	0.104	0	0.150	0.065	0.064	0						0.024	0.071	0.024	0.024	0.024	0.071	0	0	0	0.067							
	3	0	0	N/S	0.006	0.017	0						0.072	0.072	0.429	0.118	0.095	0.095	0	0	0.045	0.028							
	4	0.080	0.055	0	0.034	0	0						0.067	0	0	0.023	0	0	0.103	0.067	0.045	0.096							
	5	0.202	0	0.144	0	0.154	0.069						0	0	0	0	0	0.004	0.063	0	0.011	0							
	TOTAL	0.527	0.055	0.294	0.231	0.279	0.069						0.163	0.167	0.453	0.307	0.238	0.215	0.166	0.090	0.191	0.258							
	1	0.043	0	0.044	0	0	0	0.108	0	0	0		0	0	0	0	0	0	0	0.010	0.129	0	0.018	0.079					
	2	0	0	0.027	0.027	0.136	0.054	0.081	0.272	0.054	0.027		0.011	0	0.011	0.059	0	0	N/S	0.038	0.027	0	0	0					
	3	0	0.055	0	0	0	0	0	0	0.163	0.136		0	0	0	0	0	0	0	0.029	0	0	0	0					
	4	N/S	0	0.081	0	0	0	0.027	0.027	0	0.027		0	0	0	0.037	0.025	0	0	0.063	0.081	0	0	0.162					
	5	N/S	0.098	N/S	N/S	0.051	0.059	N/S	0.004	0	0		0.177	0.041	0.135	0	0	0.026	0.010	0	0.065	0.092	0	0.171		Stations 1 - 10	0.160		1720
	TOTAL	0.043	0.153	0.152	0.027	0.187	0.113	0.216	0.303	0.217	0.190		0.188	0.041	0.146	0.096	0.025	0.026	0.010	0.140	0.302	0.092	0.018	0.412		12 - 23	0.125		1570
	1	0	0	0.129	0.052	0.026	0.053	0.105	0.105	0	0	0		0	0.081	0	0	0	0	0	0.027	0.026	0.026	0.108					
	2	0	0.075	0.180	0.078	0	0.516	0.233	0	0.024	0	0		0.027	0.054	0	0	0	0.136	0.054	0	0.026	0	0.027					
	3	0	0.155	0	0	0.103	0.052	0	0	0	0.119	0		0.190	0.082	0	0.054	0.104	0	0.135	0	0	0.078	0.129					
	4	0.104	0.023	0	0	0.129	0.026	0	0	0	0	0		0	0	0	0.244	0	0	0.082	0.163	0	0	0					
	5	0	0	0.045	0.135	0	0.105	0.019	0.115	0.088	0	0.049		0	0	0	0	0	0	0.062	0.117	0.027	0	0		Stations 1 - 11	0.258		2380
	TOTAL	0.104	0.253	0.354	0.265	0.258	0.752	0.357	0.220	0.112	0.119	0.049		0.217	0.217	0	0.298	0.104	0.136	0.333	0.307	0.079	0.104	0.264		13 - 23	0.187		2200

Results Obtained at Heights above 5 ft at 500 yd Range

Station 8 30 ft	Station 9 150 ft	Station 10 250 ft
0.026	0.026	0
0	0	0.021
0.053	0	0
0	0	0
0.011	0	0
0.090	0.026	0.021

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TABLE 3

Deposition Results, $\mu g/m^2$: 1st Experiment

Station Number	Range, yd										
	Nominal	20	50	100	150	200	500	1000	1500	2000	3000
	Average	19	47	95	142	210	480	1110	1700	2380	3180
1		32	98	29	450	210	520	0	54	93	10
2		35	69	20	130	590	320	110	0	82	0
3		21	39	39	260	270	450	0	54	0	0
4		42	20	0	64	54	960	110	0	0	0
5			20	29	0	110	0	170	0	72	50
6		77	39	30	64	0	260	330	54	21	10
7		116	88	61	130	0	130	170	160	0	0
8		21	49	41	130	54	64	110	0	10	0
9		32	108	30	64	110	190	0	160	10	20
10		60	49	20	0	0	190	100	430	0	50
11		0	0	41	190	54	64	470	110	0	20
12		147	49	0	260	160	2440	13500	210	0	10
13		19	0	30	0	110	1050	52	0	0	30
14		19	10	20	64	0	55	260	110	20	79
15		12	0	20	130	160	280	370	0	0	89
16		0.	10	0	0	54	280	1200	0	10	20
17		4.	59	41	64	48	0	52	210	31	0
18			49	51	130	380	110		320	20	10
19						210	110		270	41	0
20						0	220		370	0	20
21						52			160	20	0
22						100			270		30
23						360			0		
24						160			0		
25						100			55		
26									440		
27									270		
28									0		
29									110		
30									160		
31									160		
Average Deposition		40	42	28	120	130	380	210	130	21	20

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TABLE 4

Deposition Results, $\mu g/m^2$: 2nd Experiment

Station Number	Range, yd										
	Nominal	20	50	100	150	200	500	1000	1500	2000		3000
	Average	19	47	95	142	210	565	1085	1620	1970	2380	3180
1		34	35	8.6	39	22	20.5	N/S		1.0	0.3	3.2
2		130	33	-	18	13	8.3	11800		-	0.7	1.7
3		540	93	10	25	22	15.5	7.9		3.1	4.8	9.3
4		980	110	9.8	13	8.9	0	6.2		8.1	2.7	5.6
5		2240	180	21	30	5.2	15	20.5		4.4	0.2	3.7
6		2960	64	12	-	7.6	12	11.0		3.2	2.8	3.5
7		3030	550	41.5	7.2	76	0		0	8.4	0.2	2.7
8		4860	385	45	23	19	6.2		0	5.4	21	122
9		3720	410	58	23	10	0.2		19.5	7.6	0.6	14
10		3480	430	36	5.2	27	0		8.1	1.1	4.7	4.4
11		1470	520	58	120	113	20		25	2.7	1.5	1.8
12		1750	440	64.5	17	25	36	7.6	24	1.9		5.5
13		2550	280	39.5	18	9.6	24	2.5	31	27.0		
14		1270	210	17	21	14	3.5	22.5	0.4	9.4		
15		1500	210	20	32	-	7.6	2.3	12	4.9		
16		1280	180	13	46	2.7	28	3.2	6.3	3.7		
17		390	250	16.5	38	12	79	1.0	5.5	6.6		
18			205	4.5		14	0	4.2	20	12		
19						31	16	0.3		7.2		
20						7.6	20	5.3		25		
21						14	6.2	2.8		6.8		
22						14						
23						73						
24						6.4						
25						51						
Average Level, $\mu g/m^2$		1890	250	26	28	21	15	7.0	15	7.5	3.6	5.0*

Note: 1. Average for 1000 yd lane does not include Station 2 values.

2. Average for 3000 yd lane does not include Station 8.

3. The somewhat scattered appearance of the array beyond 1000 yd was due to a partial movement of the array to suit weather conditions.

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TABLE 5

Summary of Meteorological Information

Experiment Number	Date of Trial Firing Time	Period	Mean Wind Speeds, ft/s, at					Air Temperatures, °C, at				Turbulence Expressed as a Standard Deviation, in degrees, of the Wind Fluctuations about the Mean						General Conditions
			Ground Level	30 ft	100 ft	200 ft	300 ft	Ground Level	100 ft	200 ft	300 ft	Period	Lateral (σ_y) at	Vertical (σ_z) at				
													30 ft	30 ft	100 ft	200 ft	300 ft	
1	27 July 1535	1535 - 1600	12.7	15.7	-	21.1	21.1	16.5	-	16.6	14.7	1535 - 1550	11.0	6.8	-	7.5	10.8	Fine: 6/8 cloud at 3500 ft
2	1 August	1500 - 1525	15.2	15.5	-	27.0	27.0	20.7	-	21.7	20.8	1500 - 1515	9.0	4.5	-	5.3	3.5	Fine: 5/8 cloud at 5000 ft

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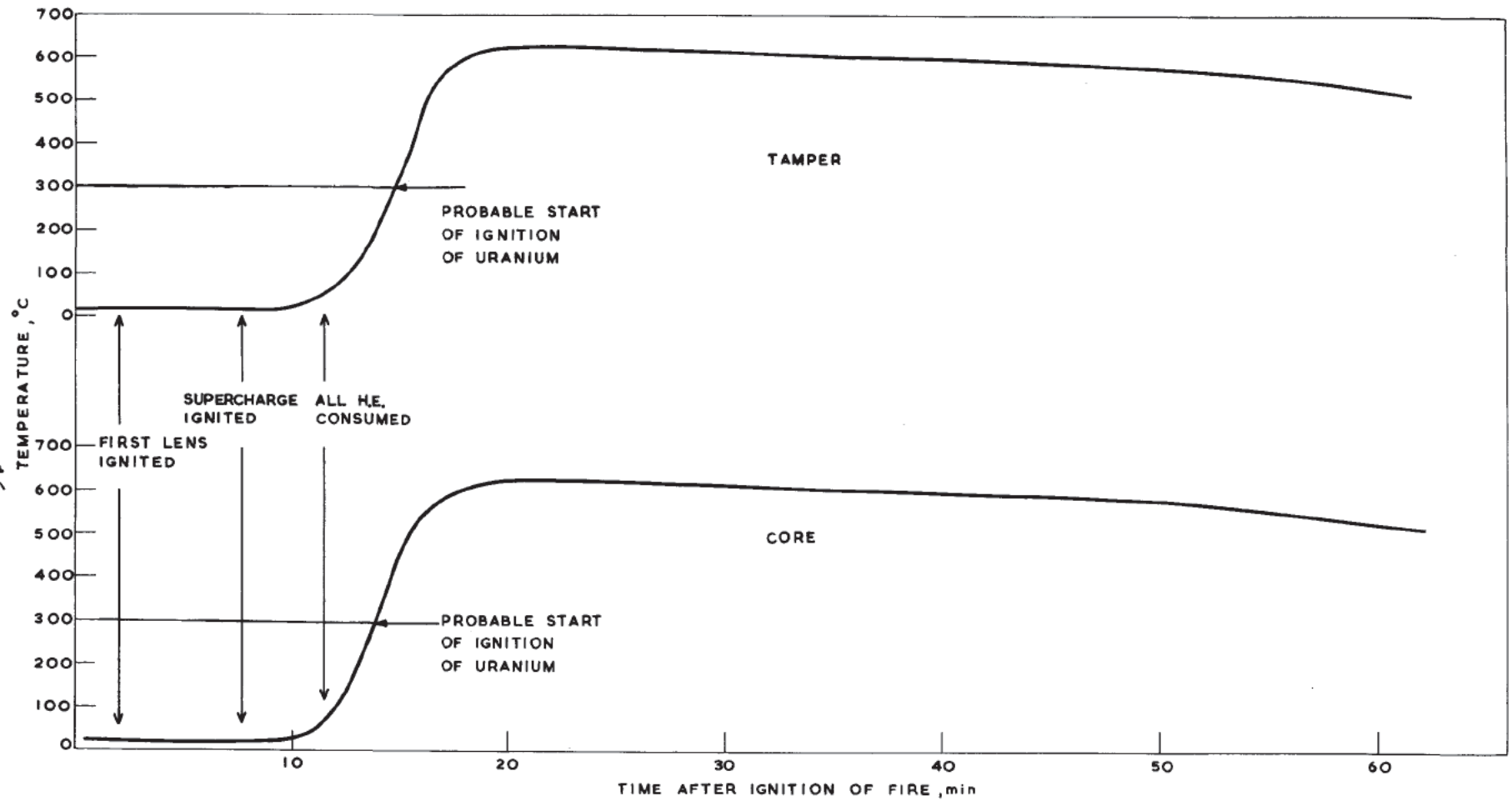

FIGURE 2. TEMPERATURE VERSUS TIME RECORDS 1st EXPERIMENT

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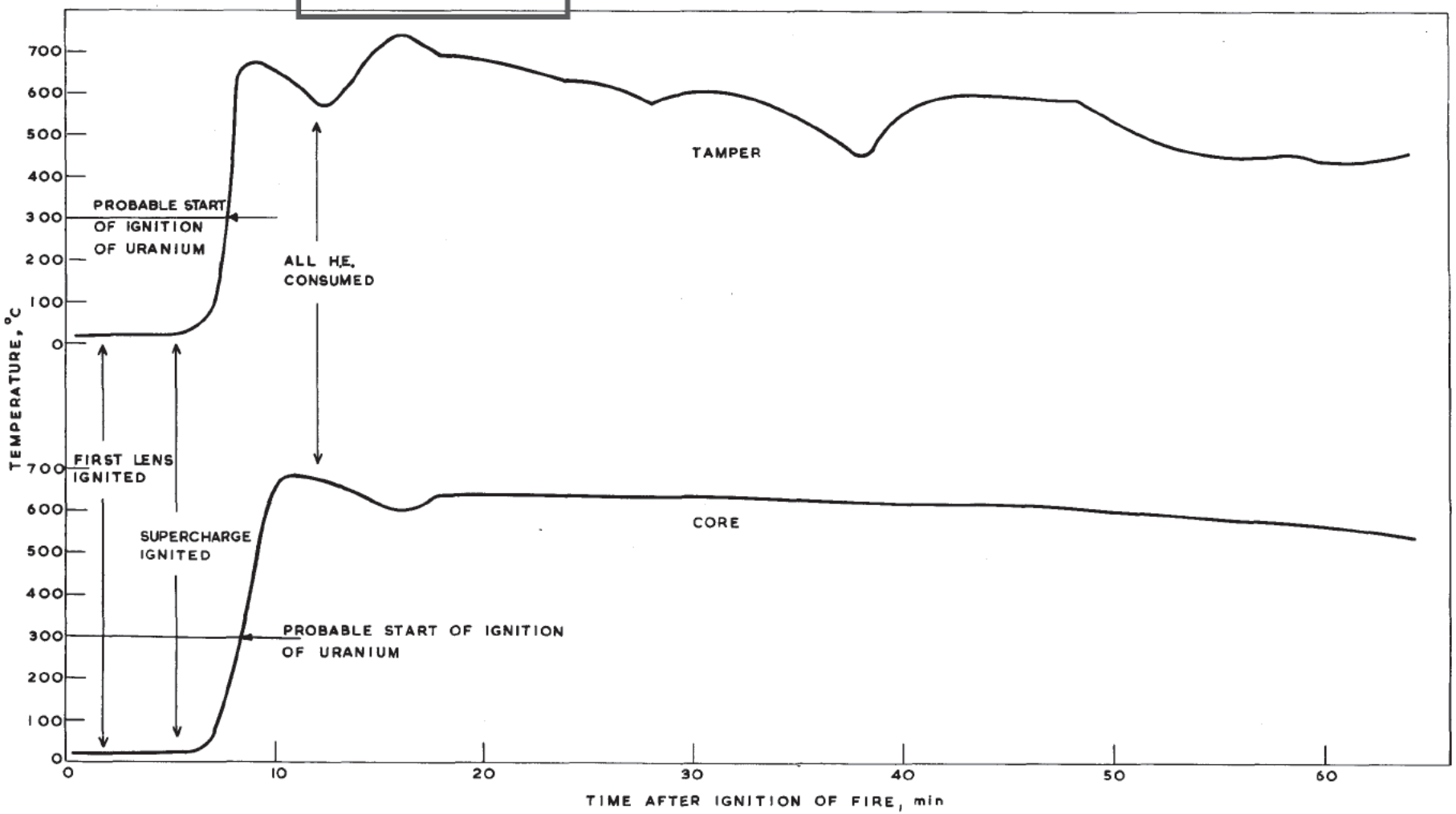

FIGURE 3. TEMPERATURE VERSUS TIME RECORDS 2nd EXPERIMENT

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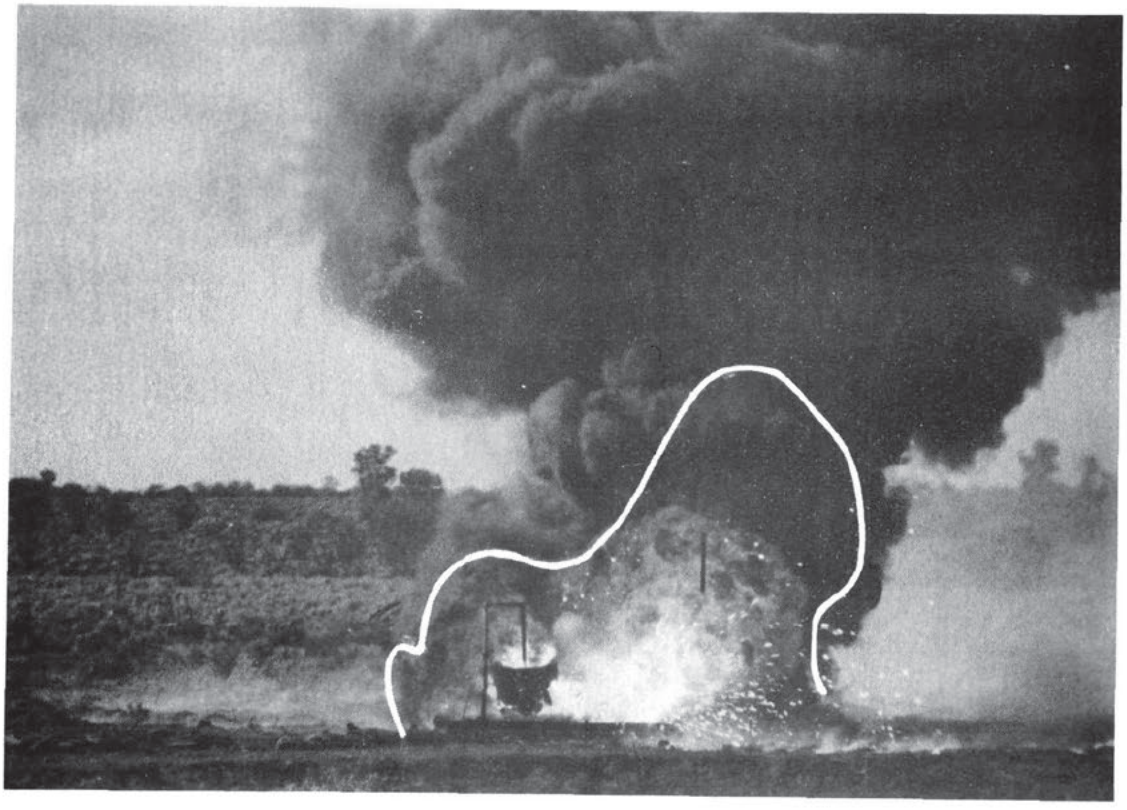

FIGURE 5. COMBUSTION OF H.E. AND FUEL IN PROGRESS

(A colour version of this photograph is held by the author)

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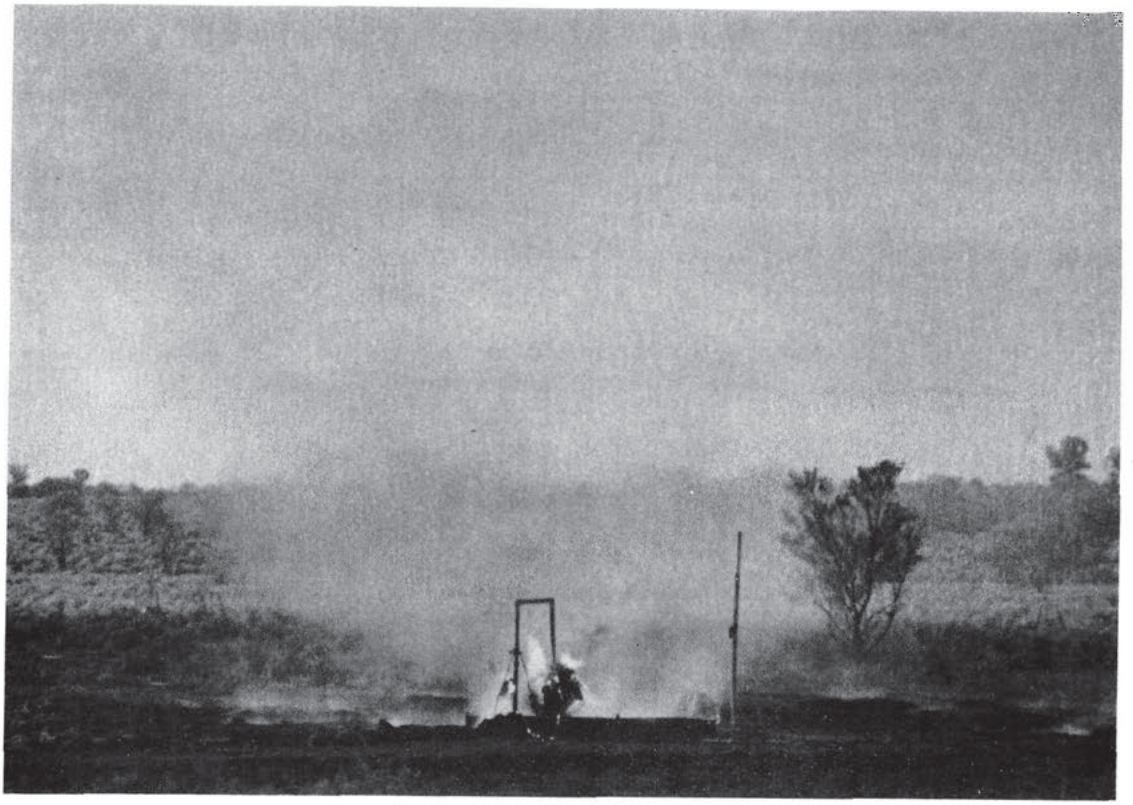

FIGURE 6. COMBUSTION OF MAGNESIUM STRONG RING

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FIGURE 7. FIRST UNIT AT COMPLETION OF EXPERIMENT

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FIGURE 8. FIRST UNIT AT COMPLETION OF EXPERIMENT

FIGURE 9. SECOND UNIT AT COMPLETION OF EXPERIMENT

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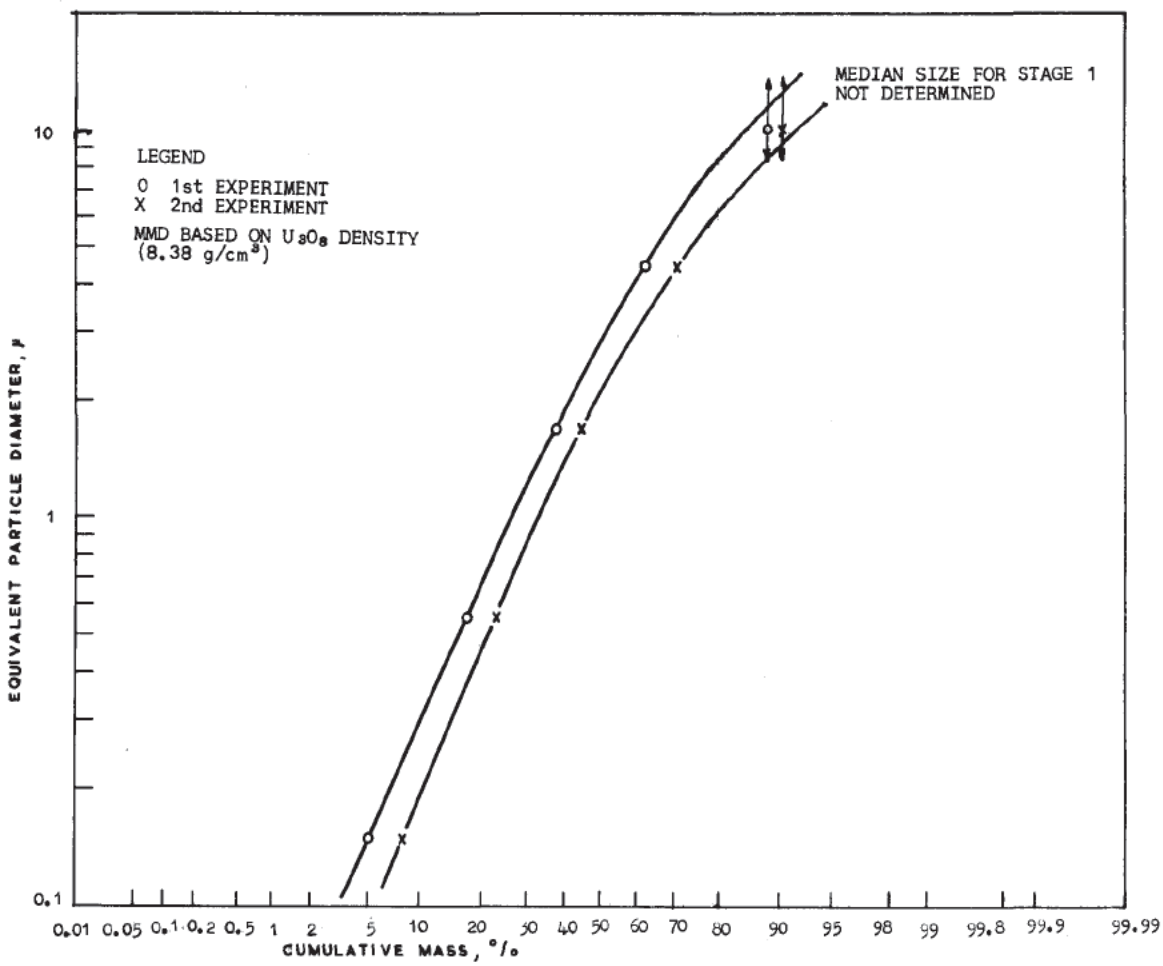

FIGURE 10. AVERAGE PARTICLE SIZE DISTRIBUTIONS
CASCADE IMPACTOR RESULTS

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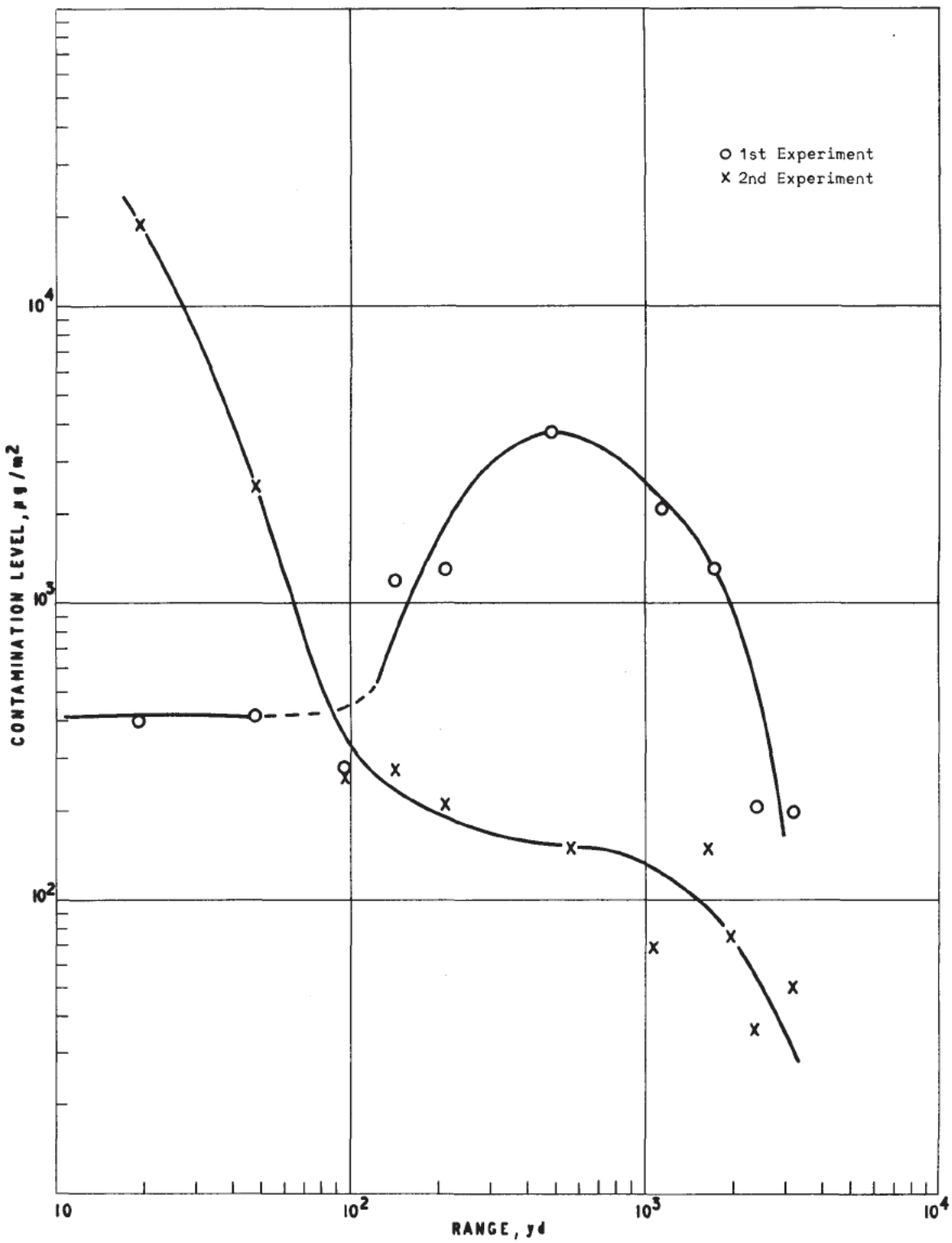

FIGURE 11. AVERAGE DEPOSITION LEVELS VERSUS RANGE

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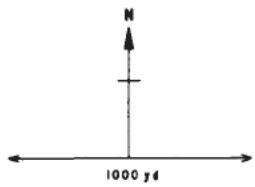

NOTE

A CASCADE IMPACTOR AND A DEPOSITION SAMPLING PLATE AT 5ft AND 3ft ABOVE THE GROUND, RESPECTIVELY, WERE PLACED AT EACH SAMPLING STATION ON THE LANES AT 200, 500, 1000, 1500 AND AND 2000yd AND WERE EVENLY SPACED. DEPOSITION SAMPLES ONLY WERE OBTAINED ON THE LANES AT 20, 50, 100, 150 AND 3000 yd

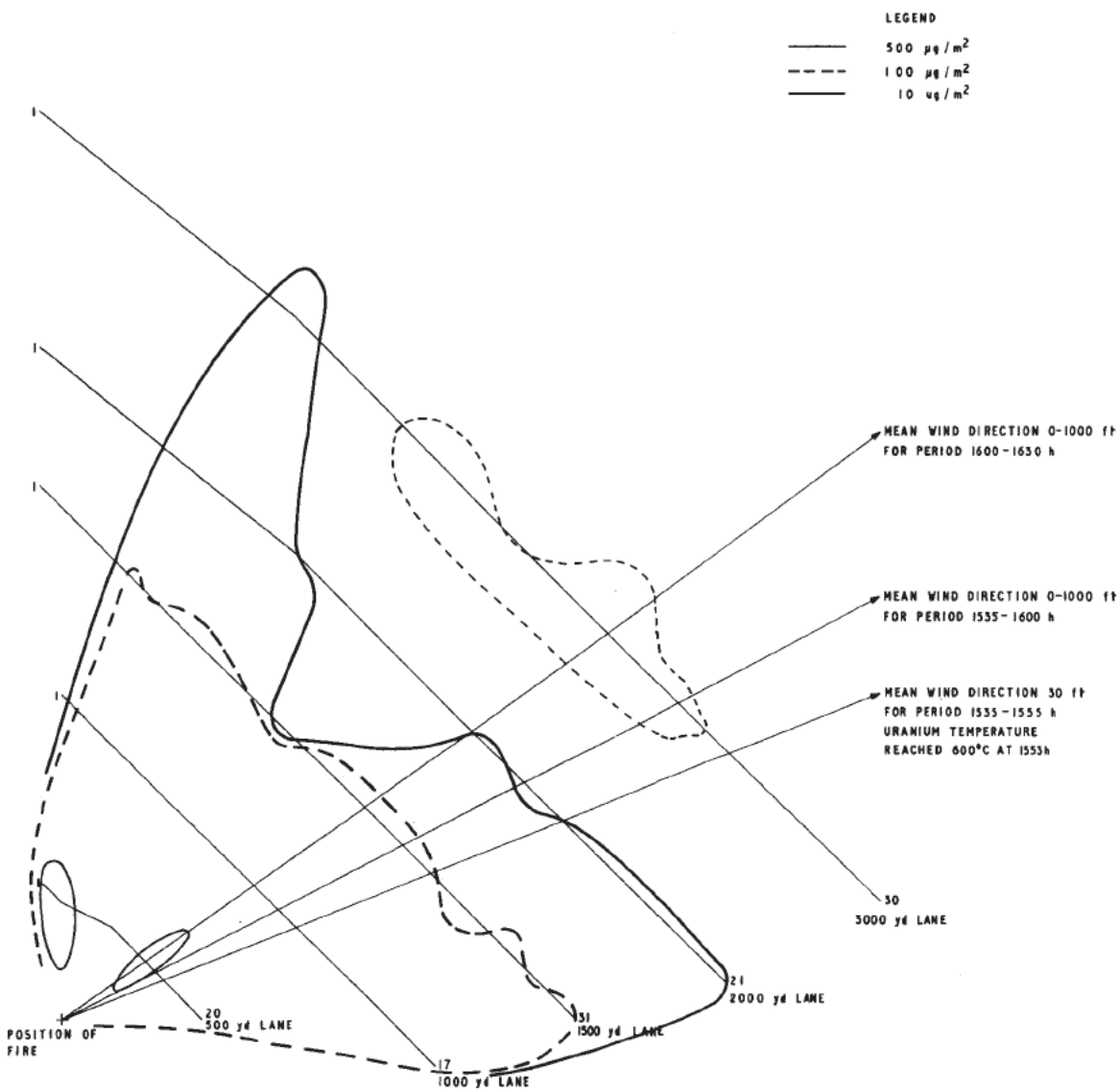

FIGURE 12. ESTIMATED FALLOUT CONTOURS

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Initial Distribution

Internal

No.		
	1	DAWRE, Dr. N. Levin
	2	DDAWRE, Mr. E. F. Newley
	3	CPA, Mr. I. Maddock
	4	CM, Mr. G. L. Hopkin
	5	CNR, Dr. H. R. Hulme
	6	CSC, Mr. R. Pilgrim
	7	CWD, Mr. W. J. Challens
	8	SSCD, Dr. F. Morgan
	9	SSCTD, Mr. P. A. F. White
	10	SSDW, Mr. R. Latham
	11	SSFD, Mr. E. H. Mott
	12	SSGS, Mr. D. E. Barnes
	13	SSMD, Mr. W. B. H. Lord
	14	SSPA, Dr. J. A. T. Dawson
	15	SSWA, Dr. A. R. Bryant
	16	SSWL, Mr. K. D. Bomford
	17	SSWP, Mr. J. R. MacLachlan
	18	SSXD, Mr. W. J. Moyce
	19	Chief Naval Representative, Capt. E. R. Manners
	20	Senior Military Representative, Col. R. Bellingham-Smith
	21	Senior RAF Representative, Gp. Capt. K. J. Powell
	22	DSSC, Mr. K. T. B. Scott
	23	DSSM, Mr. G. C. Ellis
	24	SXX, Dr. C. M. Bean
	25	ACSC, Dr. K. Stewart
	26	TA/DDAWRE, Mr. J. T. Tomblin
	27	SFE, Mr. E. R. Drake Seager
	28	SOM, Mr. E. Hinchliffe
	29	SRI, Mr. N. Pearce
	30	SWLR, Mr. A. B. Hillan
	31	WD2, Lt. Col. C. H. A. Ferguson
	32	WD3, Mr. E. J. Larby
	33	WD4, Mr. A. J. Marriott
	34	Mr. G. P. Cachia, Gp. Ldr. SXX
	35	Dr. A. E. Kay, Gp. Ldr. SRM
	36	Mr. G. C. Scorgie, Gp. Ldr. STP
	37	Mr. H. S. Weeks, Gp. Ldr. SWX (Orfordness)
	38	Mr. E. J. Chatfield, SRI
	39	Mr. A. O. Evans, DSSC
	40	Dr. E. W. Fuller, SRI
	41	Mr. J. A. Hole, HP
	42	Sqn. Ldr. I. L. Martin-Jones, Sec. WNSP

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Initial Distribution (Cont.)

Internal (Cont.)

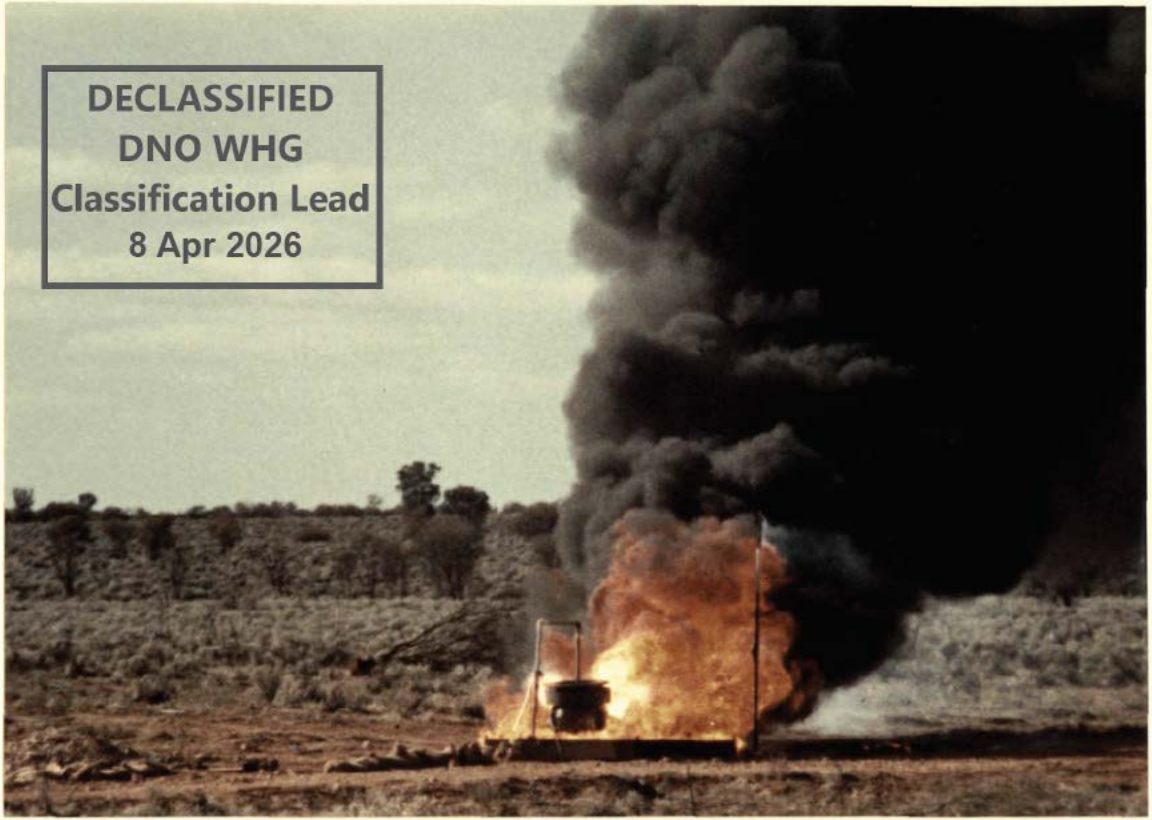
No.	43	Dr. E. B. Robertson, SRI
	44	Mr. W. N. Saxby, HP
	45	Mr. D. M. C. Thomas, SRI
	46	Sqn. Ldr. R. E. Wardrop, Sec. WESP

External

No.	47 - 51	Mr. L. T. D. Williams, DGAW, Ministry of Aviation
	52	Mr. D. C. Fakley, D. Sc.3, Ministry of Defence

Overseas

No.	53 - 67	Mr. D. C. Fakley, D. Sc.3, Ministry of Defence for JAIEG DMA, USAEC (4 copies) ACO(L) ACO(W) Dr. W. Otting, DASA (8 copies)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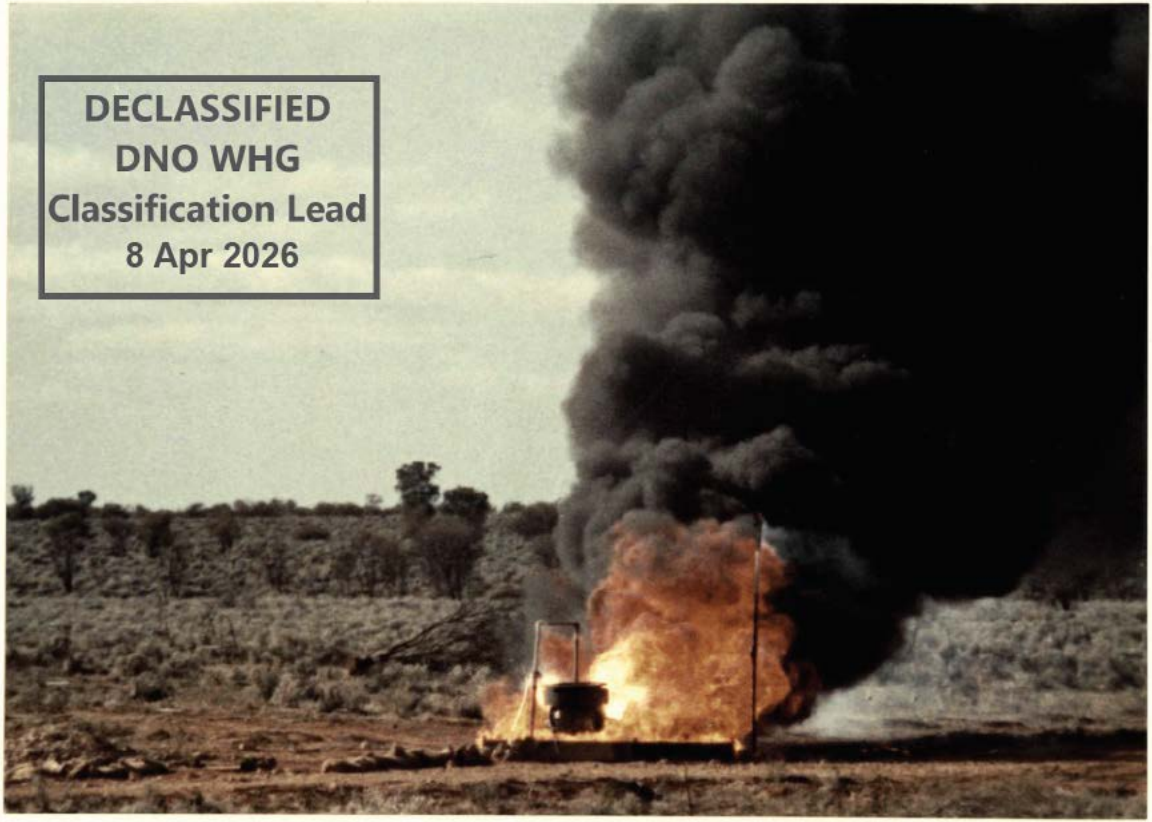
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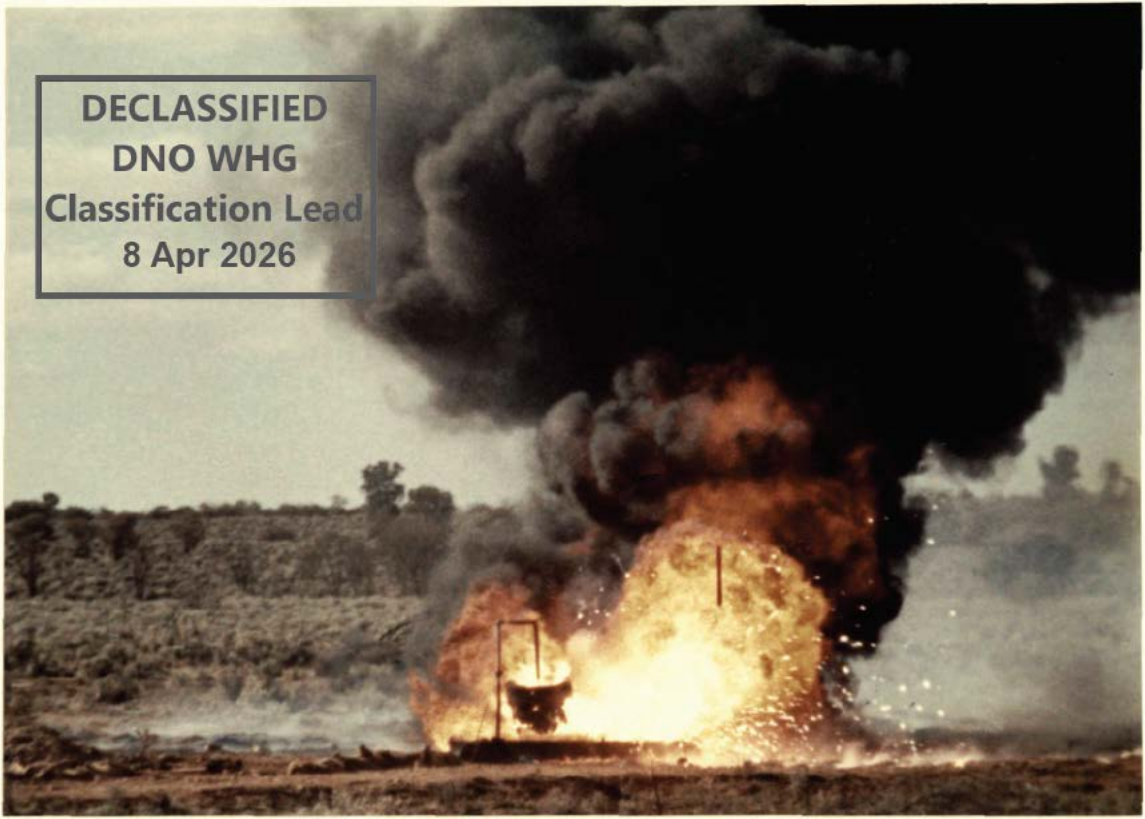
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