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AEC RESEARCH AND DEVELOPMENT REPORT

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Y-1685

Engineering and
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VACUUM PUMP EXPLOSION

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UNION CARBIDE CORPORATION

NUCLEAR DIVISION

OAK RIDGE Y-12 PLANT

operated for the ATOMIC ENERGY COMMISSION under U. S. GOVERNMENT Contract W-7405 eng 26

**UNION
CARBIDE**

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Printed in the United States of America. Available from Clearinghouse for Federal
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U.S. Department of Commerce, Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

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Date Issued: September 2, 1969

Document Y-1685

TID-4500

UNION CARBIDE CORPORATION
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Contract W-7405-eng-26
With the US Atomic Energy Commission

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ABSTRACT

An explosion occurred in the vacuum system of an electron-beam welder at the Oak Ridge Y-12 Plant. The actual initiating mechanism cannot be determined, but the explosion occurred in the discharge lines from the roughing pump.

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VACUUM PUMP EXPLOSION

INTRODUCTION

An explosion in the vacuum system of an electron-beam welder occurred on April 17, 1969 at the Oak Ridge Y-12 Plant. (a) An investigating committee was appointed to determine the cause and to recommend remedial action. Figure 1 presents an overall view of the control console of the welder and the operator's viewing window; Figure 2 gives an end view of the welder showing the access door pulled to the side; Figure 3 shows the general arrangement of the vacuum pumping system.

INFORMATION RETRIEVAL

The operators engaged in assembling and welding the part in the machine were interviewed, the welder and associated equipment were inspected, oil samples were obtained from the pumping system for analysis, and a literature search was made for pertinent information.

Comments from Employees

After interviewing the two operators and noting comments from personnel located nearby, the sequence of events can be given as follows:

A part was washed with 190-proof grain alcohol, allowed to dry, then placed in the electron-beam welder. Installation, alignment, and inspection of the part required approximately 15 minutes. During this period of time nothing was done that was not a part of the procedure that had been previously used many times. The door was moved across the opening and physically pushed into position while the clamping air cylinder was energized. The roughing vacuum valve was then opened allowing the 10-horsepower mechanical pump to begin evacuating the system. At this time, both men left the immediate area for other duties.

Approximately five minutes later, one of the operators returned to the area and noticed that the welder access door was open an estimated 1 1/2 inches (see Figure 4). While he was observing that the vacuum indicator did not show any vacuum, and before he had time to activate the switch that would change the pumping system to the "vent" position, he heard a loud, sharp noise.

(a) Operated by the Union Carbide Corporation - Nuclear Division for the US Atomic Energy Commission.

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Figure 1. CONSOLE OF THE ELECTRON-BEAM WELDER.

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Figure 2. END VIEW OF THE ELECTRON-BEAM WELDER.

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Figure 3. PUMP SYSTEM FOR THE ELECTRON-BEAM WELDER.

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Figure 4. THE PARTIALLY OPENED DOOR TO THE ELECTRON-BEAM WELDER.

Others heard the noise from as far away as 60 feet across a rather noisy production area, but no one saw any flash of light, felt a pressure wave, or sensed any unusual odors. At the same instant that the noise was heard, the mechanical pump tripped out. This pump was immediately restarted and continued running.

Next, the two men opened the chamber and inspected the part and its position, but found nothing unusual except for a slightly more than normal amount of bluish oil-type vapor in the chamber itself. The O-ring gasket around the door was found to be out of its groove and was replaced.

While attempting to pump down the system again, a leak was found around the operator's viewing window. After this leak was repaired, the system was again started up. During this time, the filament in the electron gun burned out.

Committee Observations

In addition to the information obtained through the interviews, the following observations and checks were made:

1. The lead X-ray shield on the left side of the door was deflected as though the door had been forced across it (see Figure 5).
2. The internal surface of the suction line to the vacuum system was not excessively oily or dirty (see Figure 6).
3. The valve to the bottom of the diffusion pump was inspected. It did contain a small quantity of carbonaceous deposits and clean oil (see Figure 7).
4. The system had been in operation for approximately 12 months with no oil changes in either the diffusion pump or mechanical pump.
5. The bottom of the diffusion pump gate valve was coated with oil and residue, but the gasket appeared clean and in good condition (see Figure 8).
6. The diffusion pump barrel (see Figure 9) was dirty, had lumpy residue deposits, but had no evidence of an explosion.
7. The diffusion pump jets were dirty (coated with a varnish-like substance), but were in no way bent or deflected as if from an explosion (see Figure 10).
8. During subsequent testing, the water flow cutoff switch on the diffusion pump worked only occasionally.
9. During a test with the actuating air supply removed from the slide valve cylinders, the valves were found to relax and open slightly. The valves are installed so that a pump failure will not let either the tank (roughing valve) or the diffusion pump (finishing vacuum valve) accidentally bleed to atmospheric pressure.

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Figure 5. VIEW SHOWING THE SEPARATION OF THE LEAD SHEET.

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Figure 6. VIEW OF THE SUCTION SIDE OF THE VACUUM LINE.

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Figure 7. VALVE TO THE BOTTOM OF THE DIFFUSION PUMP.

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Figure 8. VIEW OF THE BOTTOM SIDE OF THE GATE VALVE.

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Figure 9. BARREL OF THE DIFFUSION PUMP.

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Figure 10. OVERALL VIEW OF THE DIFFUSION PUMP.

10. The exhaust line from the 10-horsepower mechanical pump is a three-inch pipe that is approximately 70 feet long. A second electron-beam welder also exhausts into this same line. The mechanical pump is rated at 300 cubic feet per minute which, if both electron-beam welders are pumping down to vacuum, would give considerable back pressure in the exhaust line.

Literature Search

A literature search indicated that on several occasions similar experiences have been reported, but not documented. During the search for information, the following persons and institutions were contacted:

Dick Smith - AEC Operational Safety, Washington, DC.

Tony Sabatino - F. J. Stokes Corporation, 5500 Tabor Road, Philadelphia, Pennsylvania.

E. F. Dandrow - Linde Division, New York Production, Tonawanda, New York.

Edgar Bolles - National Fire Council, Washington, DC.

Phil Johnson - Factory Mutual, Boston, Massachusetts.

Howard Fawcett - National Academy of Sciences, Washington, DC.

ANALYSES

As stated earlier, the vacuum pumping system consists of a mechanical forepump (roughing pump), a high-speed oil diffusion pump, and a holding pump (Figure 3). Samples of the pump oils were taken for infrared analysis after the explosion to identify the types of oil in use. Results are given in Table 1. A comparison of the infrared spectra of the three oils, which were all identified as a straight-chain hydrocarbon or a type of mineral oil, is given in Figure 11.

Table 1
ANALYTICAL RESULTS FROM THE VACUUM PUMPING SYSTEM OILS

System	Infrared Identification	Flash Point (° F)	Fire Point (° F)
Mechanical Forepump	Mineral Oil	435	465
Diffusion Pump	Mineral Oil	440	480
Holding Pump	Mineral Oil	-	-

Upon draining the oil from the diffusion pump, it was observed that it had a black color and contained a considerable amount of blackish-brown sludge particulates. Centrifugation of one sample of the oil showed that approximately 0.5 cubic centimeter of solid particulates were present per 60 cubic centimeters of oil. An X-ray diffraction analysis on the centrifuged solid particulates showed the major constituent to be amorphous, but some weak diffraction lines of carbon and iron oxide were also present.

Microscopic, infrared, and additional X-ray diffraction analyses were made on various samples of solids that had been removed from the diffusion pump oil and from portions of the vacuum pumping system. Photomicrographs showing the general shape and size of the diffusion pump oil solids and residue solids removed from the bottom of the gate valve and the barrel of the diffusion pump are presented in Figure 12.

As Figure 12 indicates, two major types of charred particles were observed to be present in the diffusion pump oil. One type had an irregular shape and the other consisted of thin, flat plates. Infrared spectra of both types of solids, which indicate a cellulose material, are given in Figure 13. Microscopic examination showed that there were also some flakes of a gray paint material present. These materials were found, by X-ray diffraction analysis, to consist of titanium dioxide.

Infrared spectra of the solids removed from the barrel of the diffusion pump and the pyrolyzate or volatile material formed by heating these solids to 400° C are given in Figure 14. Infrared spectra of the solids removed from the gate valve and the pyrolyzate or volatile material formed by heating these solids to 400° C can be seen in Figure 15.

A comparison of the infrared spectra of the charred solid particulates in the diffusion pump oil, the solids removed from the barrel of the pump, and the solids removed from the gate valve shows that all these solids are similar and appear to be cellulosic in origin; eg, paper or rags. Inasmuch as a cellulose type of tissue (Kimwipes) is used for cleaning operations in the electron-beam welding process, an infrared spectrum of volatiles emitted after partially charring some Kimwipes by heating to 400° C was obtained (Figure 16). This spectrum closely resembles the spectrum of volatiles obtained by partial pyrolysis of the diffusion pump solids.

Comparative chemical analyses of the oil removed from the diffusion pump and new, unused diffusion pump oil are given in Table 2. A semiquantitative spectrochemical analysis of the oil removed from the diffusion pump after removing the particulate matter by filtering is reported in Table 3. These data show that dissolved iron (~ 60 ppm) is the principal contaminant, presumably originating from normal rust and corrosion processes.

(a) Roughing Pump

(b) Holding Pump

(c) Diffusion Pump

Figure 11. INFRARED SPECTRA OF OIL FROM THE THREE PUMPS.

(a) Two Types of Solids from the Diffusion Pump

(b) Residue from the Bottom of the Gate Valve

(c) Residue from the Barrel of the Pump

Figure 12. PHOTOMICROGRAPHS OF SOLID PARTICULATES THAT WERE REMOVED FROM THE ELECTRON-BEAM WELDING SYSTEM. (5X)

Figure 13. INFRARED SPECTRA OF SOLIDS FROM THE DIFFUSION PUMP OIL. (Upper Curve - Charred, Irregular Piece; Lower Curve - Flat, Flaky Piece)

Figure 14. INFRARED SPECTRA OF THE RESIDUE SOLIDS FROM THE BARREL OF THE PUMP. (Upper Curve - Pyrolyzate from Solids at 400° C; Lower Curve - Potassium Bromide Pellet of Solids)

Figure 15. INFRARED SPECTRA OF THE RESIDUE SOLIDS FROM THE GATE VALVE. (Upper Curve - Pyrolyzate from Solids at 400° C; Lower Curve - Potassium Bromide Pellet of Solids)

Figure 16. INFRARED SPECTROGRAM OF THE VOLATILES FROM THE PYROLYSIS OF CELLULOSE TISSUE AT 400° C.

Table 2
ANALYSIS OF DIFFUSION PUMP OILS

Test	New Oil ⁽¹⁾	Oil From Pump
Viscosity SUS at 100° F (ASTM D 88)	250.6	311.1
API Gravity at 60° F (ASTM D 287)	30.5	30.5
Flash Point, ° F (ASTM D 92)	445	440
Fire Point, ° F (ASTM D 92)	500	480
Water, Percent (Karl Fischer)	0.0028	0.0074
Neutralization Number (ASTM D 974)	0.0177	0.0351
Observed Color	Yellow	Black ⁽²⁾

(1) Convoil 20, product of the Consolidated Vacuum Company.

(2) Some charred cellulose-type solids and paint flakes found in the oil.

DISCUSSION

The sequence of events strongly indicates that the door (Figure 4) to the vacuum chamber was never fully closed. The established procedures for initiating the pump-down cycle, moving the door across the opening, and energizing the clamping air cylinder were undoubtedly followed, but there is no way of indicating automatically that proper positioning had been attained. In this instance, the operators left the area

Table 3
SPECTROCHEMICAL ANALYSIS OF DIFFUSION PUMP OIL
AFTER FILTERING

Element	Concentration (µgs/ml)	Element	Concentration (µgs/ml)
Ag	< 0.1	K	< 2
Al	2	Li	< 1
B	< 0.1	P	< 10
Ba	< 0.1	Pb	< 0.1
Be	0.1	Si	6
Ca	1	Sn	< 0.1
Cd	< 0.1	Ti	< 0.6
Co	< 2	V	< 0.1
Cr	< 0.1	W	< 1
Cu	< 1	Zn	< 6
Fe	60	Zr	< 0.2

before there would have been time for the pump to reduce the pressure to the level which would normally register on the thermocouple gage; and, during the first few seconds of the pump-down cycle, the mechanical pump would be expected to sound as if it were pumping free air. A very large leak would introduce no new effects. Without a special effort in observing the performance of the system, there would normally be no unusual evidence of a failure to fully close the door. Anyone who had just been through the normal activity of closing the door would automatically assume that a seal had been effected. There would have been no special reason to look back as a final check.

On returning from a brief period of absence, the equipment would be looked at from a different point of view; for at this time, an abnormal condition would be much more noticeable. Apparently, this unusual condition drew the attention of the operator because he observed the open door and took the proper corrective action. He started toward the console (Figure 1) to isolate the vacuum pump (Figure 3) from the chamber in order to repeat the door-closing and pump-down sequences. The occurrence of the explosion just before the pump was isolated appears to have had no connection with the actions taken by the operators. However, the fact that the operator found that the magnetic relay of the roughing pump dropped out immediately after the explosion sound was heard is regarded as most significant.

A thorough inspection of the unit after the explosion revealed little, if any, damage that might be connected with the event. The seal around the viewing window was dislodged, but this is only a gravity and adhesion seal; and, when the unit is not under vacuum, even a moderate amount of vibration can loosen it. No light flash was seen by anyone in the area nor was there any pressure wave detected. This situation would not have been true if an explosion had occurred immediately in back of the partly opened main door. It was noted that more than the normal amount of an aerosol of oil was present in the chamber after the event. This condition might be taken to indicate that the explosion had partly vented into the chamber. The fact that the gasket to the main door was out of its groove may indicate some relative motion of the door and chamber wall; the same can be said for the distortion of the lead lining. These bits of evidence are thought to indicate that the explosion occurred separate from the chamber, but may have been able to vent partly into the chamber and at least was able to impart strong vibrations to the structure.

By associating the stalling of the roughing pump with the venting of some gases into the vacuum chamber, the location of the explosion can be limited to the discharge lines of the roughing pump. The high back pressure from an explosion could have stalled the pump if the exhaust valve had been open. In fact, the rush of gas through the exhaust ports may have initiated the explosion. The pump, in moving free air from the opened chamber, would be expected to discharge a very considerable quantity of aerosol. The relatively high pressure that can be generated by the explosion of an aerosol could have forced some gas back through the seal of the pump cylinder as it was stopping the rotation of the pump. This small amount of gas could have supplied the aerosol in the chamber. Just the mechanical vibration involved in the almost

instantaneous stalling of the pump could have been enough to move the door and window. Reverberation of the explosion shock wave in the discharge piping could easily have generated all of the sound that was heard. Since the event occurred in a closed system, it would have been impossible to observe a flash. The long length and tortuous path of the exhaust line could have effectively blocked any venting of the explosion and served to raise the effective pressure at the pump.

The amount of aerosol in the exit gas from the pump may have been higher than necessary because of the age of the oil in the pump. It was pointed out by a representative of Factory Mutual that the amount of aerosol produced and the length of time the oil had been used was somewhat surprising. The oil in the mechanical pump had been in service about twice the recommended six months. Even though the duty cycle of the system under investigation may have been less severe than that for which the six-month limit had been suggested, the age of the oil must be regarded as a possible contributor to the explosion.

CONCLUSIONS

Findings

1. The explosion affecting the welding system took place in the discharge lines from the roughing pump.
2. The fuel for the explosion was the aerosol generated by the pumping of large volumes of air through the pump.
3. The large volume of air resulted from a failure to completely close the door of the welding chamber.
4. The explosion was contained by the Schedule 40 three-inch pipe used in the discharge system.
5. The age of the oil in the pump increased the amount of oil mist present.
6. The actual initiating mechanism of the explosion cannot be found.

Recommendations

1. Some indicator is needed that will reveal the condition of the chamber vacuum. This instrument should operate between atmospheric pressure and the upper range of the thermocouple gages. A large Bourdon tube vacuum gage that is easily visible to the operator is suggested.

2. The oil in the vacuum pumps should be changed as the manufacturer recommends.
3. Low-level explosions should be expected in the discharge lines of vacuum pumps, and all such systems should be designed to be consistent with the containment capability of the Schedule 40 pipe.
4. An interlock system should be considered which will prevent the activation of the vacuum system unless the chamber door is in the proper position for a seal to be effected.