REPORT NO. RN-NC-0012

INVESTIGATION OF NRO ANALOG COMPUTER FIRE
OCCURRING ON
16 AUGUST 1967

1967

1 NOVEMBER 1967

NUCLEAR ROCKET OPERATIONS

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Nuclear Rocket Operations

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W. D. Drinkwater
Assistant Manager, Administration
Nuclear Rocket Operations

Nuclear Products and Services Group

AEROJET-GENERAL CORPORATION
P O BOX 15847 • SACRAMENTO, CALIFORNIA

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INVESTIGATION OF NRO ANALOG COMPUTER FIRE
OCCURRING ON 16 AUGUST 1967

I INTRODUCTION

On 16 August 1967, at 0135 hours, the Aerojet-General Fire Department received a telephone call on emergency number 123 reporting a fire in Building 2000⁴, NRO Controls Laboratory area. The responding crew, Engine #56, found a heavy concentration of smoke issuing from the ceiling of the computer room which occupies the south section of area C-5 in the building. Openings were cut into the east and west ends of the ceiling to ventilate the area and release smoke, (Figure 1). Forcible entry was made through the west end door (Figure 2) and Fireman S. Horvath, wearing a Scott Air-Pak and lifeline, entered the room, proceeding along the corridor formed by the computers and the south wall of the room. Since the back panels of the consoles were cool to the touch, it was evident that no fire was then burning. Visual examination of the console directly below an activated sprinkler head indicated that the console had burned and that the fire was now out. The sprinkler system was shut down, and Plant Maintenance Department was requested to begin mop-up of the area. The Fire Department Report is included as Appendix A.

II. INVESTIGATION

On the morning of 16 August 1967 an investigating committee was appointed, Appendix B, for the purpose of assessing the equipment damage, determining probable cause of fire, and instituting such controls and corrective actions as deemed warranted under the circumstances to be revealed as the investigation proceeded. Concurrently, E. H. Ward, Property Accounting, opened a series of releases to a work order for the purpose of cost segregation for the various phases of work related to damage assessment, repair, and replacement for both the computing equipment and the building.

Instructions were repeated not to disturb the computer and associated equipment until further instructions were received from the Committee

Chairman. It was decided by the Committee that each of the direct participants who had knowledge of events prior to and immediately following the fire would be interviewed and a course of action decided upon after all available facts had been presented. Accordingly, a series of Committee meetings was held to interview each of the following individuals:

- R. E. Murphy, Chief, Fire Department, 1870
- E. K. Bair, Laboratory Supervisor, Control Systems Department, 7820
- A. R. Fenton, Manager, Sacramento Field Engineering Group, ComCor, Inc.
- R. E. Shore, Field Engineer, Sacramento Field Engineering Group, ComCor, Inc.
- S. J. Horvath, Fireman, Fire Department, 1870
- E. A. Sheridan, Manager, Control Systems Department, 7870

The statement of Chief Murphy revealed that the door locks were not master-keyed, therefore it was not possible for the responding fire crew to unlock the door but required that the **wire mesh window glass** in the doors be broken in order to gain entry. The air conditioning system was operating, thereby carrying away a portion of the smoke being generated. Following inspection of the area by Fireman Horvath, portable fans were placed at open doors to purge the remaining smoke and combustion products. It was found that one sprinkler head had fused and quenched the fire. Two other sprinkler heads in the immediate area did not fuse, (Figure 3). It was the opinion of Chief Murphy that the cooling air pattern from the air conditioning outlets reduced the temperature at the adjacent sprinkler heads sufficient to prevent melting of the fuse alloy.

E. A. Sheridan was the first NRO employee to arrive, reaching the lab around 3 a.m. At that time, W. R. Mulligan, Manager of Plant Engineering, was at the lab and had already notified R. B. Young and Col. L. R. Vivian, AFPRO. Mr. Sheridan notified M. M. Carness, SNPO-C, Resident Representative, and then called in E. K. Bair to take charge of the lab until the day shift arrived. Bair arrived at about 4:30 a.m. The maintenance men

were cleaning up the last of the water. The next individual to arrive, at 7:50 a.m., was A. R. Fenton. Together, Bair and Fenton examined the consoles without disturbing any part of the equipment. Bair observed that access panels on the back of ComCor console 8 were open, and that the end closure panel on the interface rack was off, (Figure 4). Bair observed a jumper cable between racks, which would have prevented the closure of the back panels, thereby confirming that these panels had to be open at the time of the fire. Had the panels been closed, it is probable that the fire would have consumed more of the interior components.

A. R. Fenton indicated in his remarks that the total maintenance effort on the shift preceding the fire had been directed to the ESIAC computer and that no work had been done on the CI 5000's. The shift turnover log indicated such instructions. R. E. Shore was the supervisor present on the swing shift on 15 August, and secured the laboratory spaces in accordance with the written ComCor procedures. Comments in the ComCor log book did not indicate any kind of problem relating to the CI 5000's. Fenton went on to describe the overnight procedure in which all main supply power is turned off and low voltage (24V) power is left on to the capacitor ovens and multiplier card heater strips. Condition of the various fuses in the circuits confirmed that main power was off and that failure occurred in the 24V circuits. The practice of maintaining heater power is common to computers of this type, since circuit stability is dependent upon the temperature stability of critical components. It was Mr. Fenton's opinion that a current of sufficient magnitude to start the fire would first have opened the circuit wires, cutting off current flow. Further, he had not been aware of presence of material in the computer which would support and propagate combustion.

Further discussion concentrated on the depth of coverage by the field service representatives, the precise maintenance processes, and the potential for restoration to service of the damaged equipment.

At present, technicians work in the laboratory on a two-shift, five days per week basis. From time to time, the crew assignments are adjusted to provide three-shift, and/or six-day coverage as the operations work load demands. Most of the technician time is devoted to testing and calibration to keep all components within specifications. Component boards are usually replaced with spare boards and the defective boards repaired by technicians. Most repairs consist of replacing resistors, capacitors, and transistors that have drifted out of tolerance. The technician crew is competent to rebuild the interface rack (Figure 5) and in the few days immediately following the fire did restore that module to service. The balance of the computer was removed from the laboratory to a bonded store location. The damaged console is shown in Figures 6, 7 and 8.

Technical investigation assignments were given to D. J. Lamvermeyer, NRO Materials Department, and A. J. Enzler, NRO Controls Department. Mr. Lamvermeyer was to classify the construction materials for combustibility and to estimate a temperature profile representing the heat distribution in the computer system. The materials report is attached as Appendix C. Mr. Enzler prepared a mode of failure analysis, and conducted limited electrical tests on the multiplier cards from the burned console (Figure 7). In addition, these investigators X-rayed suspect boards and dissected the heater sections to verify their observations. The analysis prepared by Mr. Enzler is attached as Appendix D.

Laboratory test of the multiplier board material, epoxy-impregnated glass fiber, revealed that the material would ignite, and if held in the vertical position, the flame would propagate up the board. The potting compound, Scotch Cast 221, would ignite with difficulty, but would not sustain combustion. These two materials make up the major portion of the suspect material in the computer. Electrical check of the heaters indicated one element whose resistance deviated significantly from the

specified 120 ohms. X-ray and dissection of other boards showed crossed heater wires, possible shorts to the diode terminals, and, in one, short to ground through a solder globule under the glass tape. Defects of this type could result in increased current flow, and locally elevated temperatures sufficient to ignite the surrounding material. It was not possible to provide positive proof of the precise origin of the fire, since damage at that location was so extensive as to destroy evidence of the kind required, Figure 8.

The manufacturer sent his engineering and manufacturing representatives to assist in the damage evaluation and to estimate cost and lead time for replacement of the equipment. It was decided to build the multiplier module at the factory and to re-build the logic console in the NRO laboratory. The on-site ComCor technicians are to perform the work in the laboratory, and in addition will perform the checkout of the completed assemblies after delivery.

In addition to ComCor computer damage, four Brush recorders, Model RF-1783-40, and a Boonshaft & Fuchs frequency analyzer, were heavily saturated with water from the overhead sprinkler. These pieces of equipment were removed to the Instrument Laboratory to be cleaned and checked and were subsequently returned to service without need for extensive repair.

The problem-solving schedule using the computers dictated operations which required stabilization of the electronics, therefore it became mandatory to leave power to the units around the clock. This in turn required that there be someone in attendance, since there was no reason to believe that a recurrence of the fire incident could not take place. Concurrently, an order was placed for a smoke detection system in the computer area which would provide early warning of a fire and minimize damage.

This system will be tied into the ADT alarm at the Fire Station and will actuate an annunciator in the laboratory.

III CONCLUSIONS

The fire resulted from an electrical malfunction of undetermined cause. The most probable mechanism was overheating of one or more heater strips on the quarter square multiplier boards in the non-linear rack. The fire was propagated through the chimney effect in the low density areas of the rack, spreading to the adjoining interface and function generator racks, and through the function generator rack to the upper section of the logic unit. Water deluge extinguished the fire.

We conclude, therefore, that water deluge is acceptable as a fire extinguishing agent in computing equipment. The water damage in this incident was minimized because of the rapid response of the Fire Department who shut off the water.

IV RECOMMENDATIONS

- A. Install smoke detecting equipment in the computer room and air conditioning return ducts. Consideration can be given to installation of detector units inside the consoles. This installation may involve a minor design change in the equipment.
- B. Review specifications for new equipment to assure that fire protection and/or noncombustible materials have been considered in design and construction. Provision should be made for installation of either smoke or heat detectors at appropriate places in each console.
- C. Check heater resistance and heater to ground on every module used in the computers. This check should be a standard practice before installing any circuit board using resistance heater.
- D. Determine flammability of computing equipment to be installed and take protective measures commensurate with risk.

E. Verify the adequacy of overload control through fusing devices of electrical circuits.

F. Investigate suitable mechanism for introducing water deluge to interior of computer consoles.

G. Installations not protected by around-the-clock Fire Department service should investigate use of time-limiting devices on the sprinkler system.

FIGURE 1

OPENINGS IN EAST AND WEST
END CEILING, TYPICAL

FIGURE 2
FORCED ENTRY - WEST END
DOOR. NRO LAB

FIGURE 3

FUSED SPRINKLER HEAD THAT
QUENCHED FIRE AND TWO HEADS
THAT DID NOT FUSE

FIGURE 4

OPEN ACCESS PANEL AND
INTERFACE RACK

FIGURE 5
INTERFACE RACK WITH OPEN
END PANEL

FIGURE 6

FRONT VIEW OF CONSOLE SHOWING,
LEFT TO RIGHT, INTERFACE RACK,
NONLINEAR MULTIPLIER RACK,
FUNCTION GENERATOR RACK, AND
LOGIC CONSOLE

FIGURE 7

MULTIPLIER AND FUNCTION
GENERATOR RACKS, FRONT
VIEW

FIGURE 8

BACK OF CONSOLE SHOWING
EXTENSIVE DAMAGE TO NONLINEAR
MULTIPLIER RACK AND ADJACENT
FUNCTION GENERATOR RACK AND
LOGIC CONSOLE

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APPENDIX A

FIRE DEPARTMENT REPORT

COMPANY RUN REPORT - FIRE DEPARTMENT

COMPANY Eng.	NO. 96	ALARM NO. 42-67
DATE 8-15-67	TIME 0135	
		A.M. PM

AGCS 0100-41

ALARM SIGNAL RECEIVED Fire Phone - 123	LOCATION Blkg. 20004 (Area C-5)
--	---

OCCUPANCY REON Section	SPEEDOMETER IN 19433.0 OUT 19431.3 DIFF 2.7
ORDERED HOME BY Capt. Sanders	IN QUARTERS 0340
WORKING TIME 2 HOURS 5 MIN	

CLASSIFICATION OF ALARMS			
☒ FIRE IN BUILDING	FIRE IN DUMP	FIRE ON TEST STAND	
FIRE IN BRUSH OR GRASS	OTHER FIRE OUTDOORS	NEEDLESS CALL SMOKE SCARE, ETC	
FIRE IN RUBBISH	FIRE IN VEHICLE	SPECIAL DUTY	

EQUIPMENT USED			
BACK PUMP	1	BOOSTER LINES	2
DRY CHEMICAL		GARDEN HOSE	1
CARBON DIOXIDE		1 1/2 INCH	1
WATER		2 1/2 INCH	

NAMES OF FIREMEN RESPONDING TO CALL	
S. Horvath	
F. Lehr	
A. McCauley	
B. Gericke	

LIST EQUIPMENT LOST, FOUND, DAMAGED, DESTROYED

(1) Axe - Broken handle

OTHER REPORT WITH THIS FORM ☐ YES ☒ NO	PROGRESS OF FIRE ON ARRIVAL Smoldering	YOUR CO. FIRST TO ARRIVE ☒ YES ☐ NO
--	--	---

CONDITIONS OF DOORS OR WINDOWS ON ARRIVAL (LOCKED OR OPEN, FOR EXAMPLE)

Locked

FORCIBLE ENTRY NECESSARY ☒ YES ☐ NO	WHERE Two doors - south side room.	DID YOU VENTILATE ☒ YES ☐ NO	WHERE Two holes in roof over neon sign
GALLONS OF WATER USED None (APPROX)	LOCATION OF HYDRANT Not used	CONDITION OF HYDRANT Not used	FORCED TO PASS HYDRANT (IF 'YES' EXPLAIN IN REMARKS) ☐ YES ☒ NO

REMARKS

See attached sheet.

SUBMITTED BY S. Horvath	DATE 8-15-67	OFFICER IN CHARGE P. Sanders	RANK Capt.	DATE 8-15-67
-----------------------------------	---------------------	--	----------------------	---------------------

Report - Fire - Building 20004 (Area C-5) - 8-16-67

At 0135, 16 August 1967, received a call on fire phone 123, reporting a fire in Building 20004, Area C-5, REON Section.

Responded with Engine #56 and crew. Upon arrival, found heavy concentration of smoke coming from ceiling area of REON Section, along south wall center. Immediately called in second alarm to control #2 (Fire Department) by radio from Engine #56. Control #1 was called by radio from Engine #56 requesting keys to REON Area. Both above calls were made at 0139.

Two openings were made in the ceiling of the room - one in the east and one in the west section of the Computer Room for ventilation. Following the ventilation in the ceiling, forcible entry was made at the west end door, followed by forcible entry at the east end door of the Computer Room. While the above was being done, Fire Department personnel were preparing to enter the room by putting on Scott air-pak and attaching lifeline to body. Forcible entry was made by breaking glass in top half of both doors with fire axe.

Fire Department then entered the room at the west end door, proceeded along south wall in an easterly direction until contact was made with water from the sprinkler head. Examined the area with the aid of a hand lantern; at this point, it was determined that the fire had occurred in the computer at a point approximately below the activated sprinkler head. The computer was checked by hand to determine that the heat had dissipated and the fire was out. Returned to the west door and requested that the sprinkler system be shut at the P.I.V. During the operations described above, the plant Maintenance Department was requested to cut electrical power and air conditioning.

Maintenance personnel were then requested to replace the activated sprinkler head and the sprinkler system was restored to service. Regular mop-up operations were conducted at this point and apparatus was returned to quarters at 0340 and back in service at 0400.

Additional Remarks Concerning Times:

1. 0135 = Initial alarm received by fire phone 123.
2. 0139 = Second alarm received by radio from Engine #56.
3. 0145 = Water flow alarm received thru ADT system.
4. 0157 = PIV closed.
5. 0244 = PIV opened.

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APPENDIX B

FIRE INVESTIGATION COMMITTEE

M E M O R A N D U M

16 August 1967

TO: W. D. Drinkwater, R. D. Pfremmer, C. A. DeLorenzo,
R. B. Williams, H. R. Kellenberger

FROM: W. W. Buxton

SUBJECT: Appointment to Investigating Committee

DISTRIBUTION: R. B. Young, W. R. Kirchner, J. Z. Ickes, W. D. Stinnett,
Col. L. Vivian, W. O. Wetmore, Ex-Officio Members, 0600 File

With the concurrence of your Division Manager, you have been selected to serve on the committee which will investigate the 16 August 1967 fire in the Nuclear Rocket Operation's Laboratory Building 20004.

INVESTIGATING COMMITTEE MEMBERS

	<u>Dept.</u>	<u>Ext.</u>	
W. D. Drinkwater, Chairman	7100	2072	Asst. Manager, Administration
R. D. Pfremmer	7820	4937	Supv., Control Systems Department
C. A. DeLorenzo	7030	4911	Industrial & Radiation Safety, NRO
R. B. Williams	2310	5164	Manager, Data Processing
H. R. Kellenberger	1860	7908	Manager, Manufacturing Shops

EX-OFFICIO MEMBERS

W. W. Buxton	0600	3037	Manager of Safety - Sacto. Plant
C. I. Kemper	0031	3141	Legal Representative
M. K. Wu	7030	5264	Industrial & Radiation Safety, NRO
J. Heschel	USAF	2779	Safety Officer (Observer)
E. H. Ward	0400	5245	Property Accounting
R. E. Murphy	1870	5080	Chief, Fire Department

No preliminary report is required. Preparation of the final report should be coordinated with this office.

W. W. Buxton for
W. W. Buxton, Manager
Safety
Sacramento Plant

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APPENDIX C

MATERIALS INVESTIGATION REPORT

NRO MATERIALS MEMO 67-243

To: W. D. Drinkwater
From: D. J. Lamvermeyer
Subject: Computer Fire Investigation
Distribution: L. F. Glasier, Jr., C. W. Funk, I. L. Odgers
Enclosure: (1) Computer Failure Investigation

15 September 1967

Enclosure (1) consists of detailed report of the computer failure investigation conducted by this department. It has been prepared in itemized sections for facilitating disassembly to include in other documents, as you see fit.

D. J. Lamvermeyer
Supervisor, Design and Processing Section
NRO Materials and Processes Department

Approved:

C. W. Funk
Manager
NRO Materials and Processes Department

Approved:

I. L. Odgers
Manager
NRO Engineering Division

COMPUTER FIRE INVESTIGATION

I. Introduction

ComCor C-5000 analog Computer No. 8 located in the NRO Computer Laboratory in Building 2004 was extensively damaged as a result of fire on August 16, 1967. The fire was detected at 1:30 AM and found to have activated a ceiling fire-preventative sprinkler unit (approximately five feet away) at approximately 200°F that completely extinguished the fire. The major portion of the damage was concentrated in the multiplier section, upper portions of the functional generator and interface sections of the computer. It was estimated that the fire had burned about 1 to 1.5 hours prior to detection.

Prior to and during the fire the main electrical power to the computer was turned off. However, a small amount of power was being maintained to heat 5 watt maximum heater strips that were used to maintain constant electrical component temperatures of $100 \pm 1^{\circ}\text{F}$. The heater strips were located in the multiplier printed circuit boards of the multiplier section. Hosed conditioned air was circulated through the computer sections constantly to assist in controlling overall operating temperatures. This investigation was conducted to determine (1) temperature profiles within the computer as a result of the fire, (2) flame characteristics of suspect fire origin materials and (3) potential causes and possible origins of fire.

II. Conclusions

1. The fire originated in the computer multiplier section. Heat patterns and high heat areas indicate that the fire probably started in the third level equipment rack.
2. Portions of epoxy-fiber glass circuit boards on the right and rear side of the multiplier section were completely consumed by the fire, indicating temperatures of 1100 to 1200°F for approximately one hour were sustained. Partially burned boards in the interior of the equipment racks indicated temperatures of approximately 800 to 900°F. Orientation and location of the higher temperature areas was probably caused by "chimney" draft effects that existed as a result of reduced air circulation restriction.
3. Auto-ignition and flammability tests of three suspect materials showed that the ignition point of Scotch Cast No. 221 was approximately 800°F and that the fiberglass reinforced epoxy circuit board material sustained combustion readily with the specimen length orientated vertically. When tested with specimen orientated horizontally, the results classified the material as "self extinguishing."
4. Heater strip wire assembly and construction discrepancies were found that caused reduced electrical resistance and increased heat wattage that could have initiated the fire. These included (1) heater wire that was in crossed contact and (2) heater wire that was grounded at its approximate mid-point.
5. The exact cause and origin of fire was not established.

III. Recommendations

1. Design future computers with circuit board material that will not sustain combustion. FR4 and FR5 Grade per NEMA Standards are possible material choices that are categorized as self-extinguishing.
2. Materials for computers should be qualified by Underwriter Lab tests.
3. Provide closer design and quality standards for the heater strip assembly that will eliminate the possibility of heater wire grounding or shorting.

IV. Results and Discussion

A. Temperature Profile and Origin of Fire

Visual examination of the damage indicated that the fire probably originated in the computer multiplier section which was most severely damaged as a result of evaluation of the equipment panels (See Figure 1A, 1B, 1C, 1D, 1E, 1F). The front and rear equipment panels were characterized by heat patterns that corresponded to burnt paint areas as shown in Figure 1F. The heat pattern was concentrated at the right side, front of the section and extended upward from just below the middle of the panel. A slight heat pattern was evident on the mid-section of the rear panel.

Further examination disclosed that the right side of the internal equipment racks also showed a corresponding heat pattern as shown in Figure 2. Two concentrated high heat areas were evident, one at the third and the other at the seventh equipment rack level, respectively. The two lower equipment racks experienced very little if any fire damage. The lower level high heat area (third equip-rack) is the most probable origin of fire based upon the natural upward progressive characteristics of fire as it burns.

In the area immediately adjacent to the high heat patterns and toward the rear of equipment racks, the fire had almost completely consumed the epoxy resin portion of the fiber glass reinforced circuit boards, leaving the glass reinforcement bare with almost no resin present. In contrast, the boards toward the middle of the equipment racks were charred, and partially consumed with a portion of the epoxy resin still intact.

The almost completely consumed boards represent areas that experienced higher temperatures. Temperatures as high as 1100 to 1300°F were probably present in these areas for a period of approximately one hour. The partially consumed epoxy resin areas probably experienced temperatures in the range of 800 to 900°F.

The rear and right of the equipment rack were also more susceptible to higher temperatures as a result of being less restricted to air flow. The circuit board density was less, so that less restriction was present for the circulation of air. As a result, the forced air from the air conditioner probably contributed to the complete burning of the circuit boards and higher temperatures in these areas. Thus, the heat pattern areas were not necessarily the exact areas where the fire originated but were probably a downstream result of subsequent fire damage.

B. Auto-ignition and Flammability Testing

Since the multiplier board heater strips were the only electrical components known to be functioning at the time of the fire, materials in the immediate vicinity were evaluated for ignition and flammability properties. It was hypothesized that the heater strip could be shorted by contacting itself at an intermediate length or grounding, thus shortening the electrical length of the wire and reducing electrical resistance. The current flow would then increase to cause an abnormal hot spot to ignite the adjacent or contacting material. Three materials were selected that were contacting or in the immediate vicinity of the heater strip. These included (1) Scotch Cast No. 221 polyurethane base potting compound in both vac and air cast condition (2) nylon circuit board runner material and (3) epoxy-glass reinforced circuit board material. Air cast potting compound was included to represent material used for repair of the circuit boards which necessitated removal and replacement of potting compounds in the field where vac cast facilities are not available. These materials were subjected to auto-ignition and flammability tests with procedures as follows:

Auto-ignition

A .2 gm sample was subjected to temperatures up to 1290°F in an air atmosphere. Temperature is applied at a rate of 18°F/min. Flash or ignition temperature is observed and recorded.

Flammability - per ASTM D-635-63

Materials length was held horizontally. Flame was applied two times for a duration of 30 seconds each. Test conducted in still air.

Criteria:

Non burn - less than 1" of sample burns

Self extinguishing - more than 1" but less than 4" is burned

Burn - material burns beyond 4" length at rate of inch per second

The results of the tests are summarized in Table I and show that it is possible to ignite the potting compound material and sustain combustion by burning of the circuit board material. The 800°F temperature required to ignite the potting compound is high in comparison to the thermostatic-controlled 100 ± 1°F of operation and does not appear to be a probable mode of failure. However, a shorted or grounded heater wire assembly could have readily reached or exceeded this temperature as a result of increased heat wattage.

The circuit board material burned readily in the vertical test position and was self-extinguishing in the horizontal test position. Since the circuit boards were aligned vertically in the equipment racks, fire spread from the origin by progressive burning of the boards that sustained the fire, and caused the majority of damage.

C. Origin and Cause of Fire Investigation

Investigation was conducted to determine the origin and cause of fire. The heater strip circuit from all of the multiplier circuit boards were tested for continuity and resistance to ground and to itself. The unshorted and ungrounded heater strip length was found to have a resistance value of 120 ohms. Of the 96 multiplier boards tested and inspected, six were found to be suspect as follows:

BOARD LOCATION IN MULTIPLIER SECTION

<u>Board No.</u>	<u>Rack Position (A to H/low to high)</u>	<u>1 to 12 (right to left)</u>	<u>Results</u>
1	(ABC) A or B or C Undetermined	(U) Undetermined	80 ohms between heater terminals
2	D	12	Infinite resistance between heater terminals
3	E	7	2000 ohms between heater terminals
4	F	4	Infinite resistance between heater terminals
5	F	11	Shorted to ground with one terminal with 45 ohms to ground and the other 80 ohms to ground
6	H	1	120 ohms-heavy fire damage

Each of the boards were x-rayed to determine heater strip wire position and integrity. The wires on Board No. 1 were found to be crossed and contacting as shown in Figure 3, thus accounting for the lower resistance values. However, there was no char or burnt material associated with the contact area that would suggest it as an origin of fire. Boards 2, 3, 4 and 6 were found to have normal heater wire orientation within the heater glass fiber enclosure. The high and infinite resistance was found to be caused by burnt or char material at the wire terminal ends, that prevented proper contact during the resistance tests. Radiographs of Board No. 5 showed a somewhat erratic wire pattern as shown in Figure 4. Disassembly of the heater strip indicated that the strip had made contact with ground as indicated by the small char area as seen in Figure 5. Further dissection indicated that the wire had made contact with a small piece of solder that was below the char area shown and that the solder was grounded. Dissection of Board No. 6 showed that the fire damage had penetrated from the exterior of the board,

thus eliminating it as a possible origin of fire. The results indicate that heater strip discrepancies were sufficient to cause electrical short circuiting that could cause hot spots and subsequent fire.

Although discrepancies were revealed in the heater strip, construction and assembly, the origin of fire was not established. The extensive damage caused by the fire probably destroyed the evidence that would have conclusively established the origin of fire.

TABLE I

RESULTS OF AUTO-IGNITION AND FLAMMABILITY TESTS

<u>MATERIAL</u>	<u>AUTO-IGNITION TEMPERATURE</u>	<u>FLAMMABILITY CHARACTERISTICS</u>
Scotch-Cast No. 22	860°F	Non-Burn
Air Cast	860°F	Non-Burn
Vac Cast	800°F	Non-Burn
Nylon Runner	986°F	Non-Burn
Epoxy-resin fiber glass circuit board	No ignition up to 1290°F	Self-extinguishing - 1.5" total length burned Specimen in vertical position burned readily. Approx. 1 Inch/ 10/sec

FIGURE 1A

OUTSIDE FRONT AND REAR PANELS
OF INTERFACE SECTION SHOWING
HEAT PATTERN ON REAR TOP
CORRESPONDING TO VOID AREA IN
INTERFACE SECTION.

FIGURE 1B

OUTSIDE END PANEL OF INTERFACE
SECTION SHOWING DRIP LINE AND HEAT
PATTERN THAT INDICATED PANEL WAS
OFF AND RESTING AGAINST TABLE
AT TIME OF FIRE.

FIGURE 1C

INSIDE END PANEL OF INTERFACE
SECTION SHOWING HEAT PATTERN
AT TOP CORRESPONDING TO VOID
AREA IN INTERFACE SECTION.

FIGURE 1D

INSIDE OF FRONT AND REAR PANELS OF
INTERFACE SECTION SHOWING LAT
PATTERN IN REAR TOP CORRESPONDING
TO VOID AREA INSIDE

FIGURE 1E
INSIDE FRONT AND REAR PANELS
OF MULTIPLIER SECTION SHOWING
HEAT PATTERNS AT FRONT AND
REAR TOP.

FIGURE 1F
OUTSIDE OF FRONT AND REAR PANELS
OF MULTIPLIER SECTION SHOWING
HEAT PATTERN ON FRONT RIGHT SIDE

FIGURE 2 - MULTIPLIER COMPONENT
RACKS STACKED IN POSITION
SHOWING HEAT PATTERN AND TWO
HOT AREAS ON RIGHT SIDE

FIGURE 2 - MULTIPLIER COMPONENT
RACKS STACKED IN POSITION
SHOWING HEAT PATTERN AND TWO
HOT AREAS ON RIGHT SIDE

B

FIGURE 3

X-RAY OF CIRCUIT BOARD FROM
ABC - UNDETERMINED POSITION
SHOWING CROSSED CONTACT
HEATER WIRE

FIGURE 4

X-RAY OF CIRCUIT BOARD F-11
SHOWING ERRATIC HEATER WIRE
PATTERN.

FIGURE 5

Char area in glass tape found under the heater wire from circuit board F-11. Dissection disclosed a piece of solder just below the tape that had made contact with the heater wire to short it to ground and cause localized heat and char.

MAG 45X

RN-NC-0012

APPENDIX D

MODE OF FAILURE ANALYSIS

APPENDIX D

MEMORANDUM

TO: W. D. Drinkwater

FROM: A. J.ENZLER

SUBJECT: Computer Fire Investigation

DATE: 20 October 1967

Summary

An attempt was made to pinpoint the origin and cause of the fire. This was not accomplished. Several potential fire causing anomalies were uncovered. Corrective actions are recommended.

Investigation

This investigation was initiated after the computer had been removed from the computer room. Much of the computer had been disassembled. It appeared that the fire had started in the front right corner of the second tray from the bottom. This is not conclusive because it is quite possible that the fire started at a higher level and propagated down as well as up even though a forced air flow was up. This possibility is suggested because both the epoxy used in the glass terminal boards and the potting compound used on the boards melt and drip readily when heated. Dripping, flaming liquids would propagate the fire down. There is some indication that this was the case. Metal frames and covers indicate hot spots at the third level and at the top of the rack.

There are two areas in the circuitry that generate or could generate appreciable power. One is the output amplifier load resistors, and the other is heater strips used to temperature stabilize groups of diodes. The output amplifiers were supposed to have been off, and it is fairly conclusive that they were because the power supply for this section contained seven fuses. None of these fuses were blown. There are only two possibilities how the computer could have been left on and the fuses not blown. One is someone replaced the fuses. The other is the fire burned the A. C. leads to the fans and caused the computer's main supply circuit breaker to trip before any other wire burned enough to blow a fuse. Both of these possibilities seem remote.

The computer must have been in standby condition. In standby the computer has two other power supplies that remain turned on. Each of these supplies had one fuse, both of which were blown. These two supplies energize 48 cards each. Mounted on each of these cards is a heater composed of nickel-chromium wire sandwiched between glass tape. See the attached sketches. The heater is designed for 24V and 5W. It was connected to 18 volts so it would dissipate about 3 watts. This is insufficient power to ever cause heating to the extent

of starting a fire or even cause the board to reach 200°F (estimated). If part of the heater were shorted the temperature would rise. For example if a short occurred where only one-fourth of the heater were across the full voltage, the wattage would increase by four in one-fourth of the wire. As a first order approximation this would increase the wire temperature by a factor of sixteen. Investigation of six boards by X-ray showed one case where part of a heater was shorted by crossed heater element wires. This heater element measured about 80 ohms compared to about 120 ohm nominal. It did not start the fire but indicates the lack of quality control and shows this problem does exist. There is no reason why a much greater change could not occur.

A second possibility of shorting out the heater is for part of the element to not be included between the glass tape insulation and extend out against a diode lead that is grounded. X-rays indicate that this is quite possible. None were found in the six boards X-rayed.

A third possibility was found through ohmage checks. Ohmage checks were made on all the boards and all elements measured about 120 ohms except the one partially shorted that measured 80 ohms. All boards were then checked to ground, and one was found that measured about 40 ohms to ground from one end of the heater element and about 80 ohms from the other end. This board revealed, when dissected, that a sharp point of solder on the ground clad plate had penetrated the glass insulation and connected with the heater element. There was a small area of charring around the point of contact (see Figure 5 of Appendix C). This board did not start the fire.

An attempt was made to ignite samples of fiberglass board and pieces of the potting compound by clamping a piece of heater wire against the samples and applying current to the wire. The current was adjusted to heat the wire to a cherry red. The fiberglass board charred, and after about two and one-half days the wire element broke. The instant the element broke flaming combustion commenced. A similar test but shorter in duration on the potting compound did not produce flame. It only melted or charred. Tests of longer duration may have produced flame.

One of the probable sources of fire in the computer is essentially not fused even though there is a 10 amp fuse in the circuit. A fuse is not a very accurate device. The burnout current may vary 25% depending on time, mounting conditions and ambient temperature. If multiple identical loads are supplied from one fuse, the variation in fuse capacity will limit the ability of the fuse to protect between normal and overload of any one circuit. For example, if there are 48 0.2 amp loads, the fuse must be 10 amps, but it may not blow if the load is increased to 12.5 amps because of fuse tolerances. Therefore, it follows 47 loads may remain at 0.2 amps and the 48th one may increase to 3.1 amps. It is even worse for the on-off heater type circuit in the computer because the fuse has to be sized large enough to supply all heaters from a cold start and if it is assumed that after warmup half of the heaters are off then the faulty heater could draw 28.5 times rated current. Rated current is about 0.2A.

$$0.2 \times 38.5 = 7.7 \text{ Amps}$$

This may be insufficient to blow a 10A fuse, yet raises the current in one board by a factor of 38.5. Current of this magnitude would immediately melt the nickel-chromium element. (Melting point 2460 F.)

More fire resistant construction materials in addition to separate fuses would also alleviate the problem. Such materials are available. Heat and/or smoke sensors and alarms built into the computer could also be used.

A handwritten signature in cursive script, reading "A. J. Enzler".

A. J. Enzler
Control Systems Department
Nuclear Rocket Operations

COMPUTER MULTIPLIER BOARD