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ROCKET ENGINE OPERATIONS - NUCLEAR

SNPO-C NOZZLE DESIGN REVIEW

January 22, 1964

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PROGRAM OF PRESENTATION

1. RN-6 INTEGRATION
2. NOZZLE (CAST & FORGED) PROGRAM CONSIDERATIONS
 - a. JACKET COOLING
 - b. STRUCTURES
 - c. LEAKAGE
 - d. SIMULATION
 - e. LIFE
 - f. HYDROTEST, COLD FLOW, SIMULATION, NUCLEAR
3. CONFIGURATION SELECTION, CRITERIA, AND SCHEDULE

Chart 1

NERVA PROGRAM

RN-6 NRX-A1 PERT NETWORK

Chart 2a

NERVA PROGRAM

RN-6 NRX-A1 PERT NETWORK

Chart 2b

NERVA PROGRAM

STATUS OF RN-6 NOZZLE AND ASSOCIATED EQUIPMENT

(AS OF 14 JANUARY 1964)

<u>COMPONENT</u>		<u>AVAILABILITY DATE</u>
1.	RN-6 NOZZLE	7 FEB. '64
2.	RN-6 INSTRUMENTATION	
	a. P, T, & VIB (INSTRUMENTATION DATA BOOK)	15 FEB. '64
	b. BIAXIAL STRAIN GAGES	15 FEB. '64
	c. THERMOCOUPLES	15 FEB. '64
3.	RN-6 GROUND SUPPORT EQUIPMENT	
	a. HANDLING SLING	15 FEB. '64
	b. NOZZLE STAND	15 FEB. '64
	c. PRESSURE TEST PLUGS	15 FEB. '64
	d. THROAT PLUG	15 MAR. '64
4.	RN-6 PROPELLANT FEED LINE	13 DEC. '63
5.	RN-6 MISCELLANEOUS HARDWARE	
	a. AGC	13 DEC. '63
	b. ROCKETDYNE	7 FEB. '64

Chart 3

NERVA PROGRAM

NRX-A1 NOZZLE COMPARISON

	LEAKAGE	STRUCTURAL	HEAT TRANS.	JACKET - TUBE INTERFACE
AEROJET CAST JACKET	MINIMUM INTERNAL LEAKAGE TOLERATED IF EXTERNAL LEAKAGE CANNOT BE REPAIRED STRIP & RECAST ON SAME TUBE BUNDLE (HAVE DONE 3 TIMES ON NOZZLES)	HAVE HYDRO PROOF TESTED NOZZLE CHAMBER TO 780 PSI (NOZZLE INLET TO THROAT PLUG)	SIMULATION TEST FEB., 1964	COOLING JACKET DEPENDS ON BOND BETWEEN CASTING AND TUBE AROUND INTERLOCK. 100% CONTACT IS POSSIBLE AROUND INTERIOR OF SHELL
ROCKETDYNE RN-6	MINIMUM INTERNAL LEAKAGE TOLERATED EXTERNAL LEAKAGE DUMPED OVERBOARD FROM VALLEYS BETWEEN TUBES UNDER JACKET TUBE BUNDLE NOT SALVAGABLE	CANNOT HYDROTEST CHAMBER ABOVE 50 PSI. REQUIRED THROAT PLUG NOT DESIGNED	SIMULATION TEST MARCH, 1964	COOLING JACKET DEPENDS ON BRAZED JOINT BETWEEN JACKET AND TUBE 50% CONTACT MAX. POSSIBLE AROUND INTERIOR OF SHELL.

Chart 4a

NERVA PROGRAM

NRX-A1 NOZZLE COMPARISON

	LIFETIME OPERATIONS	NRX-A1 REQUIREMENTS
AEROJET CAST JACKET NOZZLE	DESIGNED FOR LARGE NUMBER OF REPEATABLE FIRINGS	PORTED FOR PHOTO- GRAPHIC COVERAGE OF CORE WILL BE COLD FLOW TESTED AT LRP AND SHIPPED TO NRDS 27 JAN. 1964
ROCKETDYNE RN-6 NOZZLE	LIMITED RESTART REFIRE CAPABILITIES DUE TO INCONEL X PROPERTIES	UNPORTED - NO PHOTO COVERAGE OF CORE WILL NOT BE COLD FLOW TESTED PRIOR TO SHIP- MENT TO NRDS 7 FEB. 1964

Chart 4b

NERVA PROGRAM

NRX-A-1 NOZZLE DEVELOPMENT STATUS AND SCHEDULE

S/N 0011 CASTING COMPLETE - 23 OCTOBER 1963
FABRICATION COMPLETE - 19 DECEMBER 1963
TESTING COMPLETE - 24 JANUARY 1964

POTENTIAL ALTERNATIVES

S/N 0010 AVAILABLE

S/N 0004 AVAILABLE

S/N 0007 AVAILABLE 24 FEBRUARY 1964

S/N 0006 AVAILABLE 17 FEBRUARY 1964

NERVA PROGRAM

NRX-A-2, 3, 4 NOZZLE DEVELOPMENT STATUS AND SCHEDULE

UNIT	CASTING DATE	COMPLETION DATE	TESTING COMPLETED
S/N 0012	17 JAN 1964	9 MARCH	25 MARCH
S/N 0015	7 FEB	1 APRIL	25 MAY
S/N 0016	13 MARCH	15 MAY	27 JUNE

NERVA PROGRAM

HOT-BLEED NOZZLE DEVELOPMENT STATUS AND SCHEDULE

UNIT	CASTING DATE	COMPLETION DATE	TESTING INITIATED
S/N 0013	31 JAN 1964	15 APRIL	5 MAY
S/N 0014	15 MARCH	25 MAY	3 AUGUST

NERVA PROGRAM

PROGRAM FOR QUALIFICATION OF CAST NOZZLE

TASK	JAN	FEB	MAR
LEAKAGE PROGRAM COMPLETE		<div> <div></div> <div>FEB 1</div> </div>	
CONDUCTANCE ACCEPTANCE TEST			
S/N 2H OR S/N 004	<div> <div>JAN 28</div> <div></div> </div>	<div> <div>FEB 12</div> <div></div> </div>	
SN 012			<div> <div>MAR 9</div> <div></div> </div> <div> <div>MAR 15</div> <div></div> </div>
STRUCTURAL ACCEPTANCE TEST			
SN 006		<div> <div>FEB 19</div> <div></div> </div> <div> <div>FEB 29</div> <div></div> </div>	
SN 012			<div> <div>MAR 15</div> <div></div> </div> <div> <div>MAR 25</div> <div></div> </div>

LEGEND: SCHEDULED START
 SCHEDULED COMPLETION

NERVA PROGRAM

POTENTIAL LEAKAGE AREAS

BOLT COOLANT FITTING SEAL CONCEPT

THERMOCOUPLE PASS-THROUGH SEAL CONCEPT

TINKER'S-DAM-TO-TUBE BUNDLE SEAL CONCEPT

AFTER FURNACE BRAZING, CAVITIES ARE
PACKED WITH CRES STEEL WOOL AND HAND
BRAZED USING EASY FLO 45

SILVER RING CONCEPTS

HOT BLEED PORT SEAL CONCEPT

CAST JACKET COOLING REQUIREMENTS

NERVA PROGRAM

CAST JACKET COOLING REQUIREMENTS

COLD FLOW TEST SECTION

0.440 IN. O.D. X 0.014 IN. WALL
CRES 347 TUBES

WIRE INTERLOCK EFFECTIVE CONTACT CONDUCTANCE

NERVA PROGRAM

NUCLEAR HEATING ANALOGY TEST SECTION

PHYSICAL MODEL FOR ACCEPTANCE TEST ANALYSIS

JACKET-TO-COOLANT TUBE INTERFACE.
A UNIFORM CONDUCTANCE APPLIES
OUTSIDE THE GAP REGION

ADDITIONAL PHYSICAL MODELS FOR ACCEPTANCE TEST ANALYSIS

- GAP CONDUCTANCE NOT EQUAL TO ZERO
- TWO INTERACTING GAPS
- VARIABLE JACKET THICKNESS
- ROUND GAP REGION

STEADY-STATE NUCLEAR OPERATION

ACCEPTANCE TEST TEMPERATURE RESPONSE

ACCEPTANCE TEST CONDUCTANCE PENALTY

TIME = 180 sec

JACKET THICKNESS = 0.875 in.

NRX-A NOZZLE SIMULATION CONDITIONS

Heat Flux Profile

COOLANT CORRELATION:
REGIME B - THROUGHOUT

—— NRX-A NUCLEAR OPERATIONS
---- LO₂/LH₂ SIMULATION
MR=6.0

NRX-A NOZZLE SIMULATION CONDITIONS

TUBE MARGINS OF SAFETY

TUBE MARGINS OF SAFETY

NERVA NOZZLE ALUMINUM CAST JACKET MERIDIONAL STRESSES

NERVA NOZZLE ALUMINUM CAST JACKET HOOP STRESSES

SUMMARY OF CRITICAL CONDITIONS - ALUMINUM JACKET NOZZLE

CONDITION	CHAMBER PRESSURE (psi)	FLG AV TEMP (°F)	$M \frac{\text{in. lb}}{\text{in.}}$	$Q \text{ (lb/in.)}$	$V \text{ (lb/in.)}$	ULTIMATE MARGIN OF SAFETY	CRITICAL FLG THICKNESS (in.)
HYDROTEST	800	+70°	-2480	7420	8500	1.0	1.59
COLD FLOW	100	-340°	(T & P) 6951	3454	1021	0.20	1.29
SIMULATION	700	-350°	(P)-1564 (T) $\frac{2606}{1042}$	(P) 6689 (T) $\frac{355}{7044}$	7188	0.92	1.59
SIMULATION	800	-350	(P)-1800 (T) $\frac{2606}{806}$	(P) 7650 (T) $\frac{355}{8005}$	8200	0.68	1.59
A-2 (REACTOR)	700	-340°	(P)-1147 (T) $\frac{1895}{749}$	(P) 6444 $\frac{263}{6707}$	7188	1.06	1.59

EVALUATION OF NOZZLE LIFE

Sheet 1 of 2

I. TUBES

PRIMARY CONSIDERATIONS:

1. THERMAL STRESS FATIGUE
2. INDUCED STRESS LEVELS VS CREEP RUPTURE

THERMAL STRESS FATIGUE

$$N^{1/2} \Delta \epsilon_p = C, \quad \begin{array}{l} N = \text{NUMBER OF CYCLES TO FAILURE} \\ C = \text{MATERIAL CONSTANT WHICH IS A FUNCTION} \\ \text{OF TEMPERATURE} \\ \Delta \epsilon_p = \text{TOTAL STRAIN} \end{array}$$

FOR REGIME B, $N = 3720$ CYCLES
FOR REGIMES A AND B, $N = 205$ CYCLES

EVALUATION OF NOZZLE LIFE

Sheet 2 of 2

MAXIMUM INDUCED STRESS LEVEL AND CREEP RUPTURE STRENGTH

FOR REGIME B,

CRITICAL POINT $\left\{ \begin{array}{l} \sigma = 7510 \text{ psi} \\ \text{TEMP} = 667^{\circ}\text{F} \end{array} \right.$
AT STA 30.18

FOR 0.010% PER 1000 HR, CREEP STRENGTH = 24,000 psi.
RUPTURE TIME = ∞ .

FOR REGIMES A AND B,

CRITICAL POINT $\left\{ \begin{array}{l} \sigma = 8150 \text{ psi} \\ \text{TEMP} = 1348^{\circ}\text{F} \end{array} \right.$
AT STA 30.18

FOR 1350°F AT 8,150 psi, RUPTURE TIME = 10,000 HR

II. ALUMINUM JACKET

FOR A-356-T6 MATERIAL WITH YIELD AND ULT STRENGTHS OF 25
AND 35 KSI RESPECTIVELY, THE FATIGUE STRENGTH OF 2500 CYCLES
OF FULLY REVERSED BENDING IS 25 KSI.

AXIAL STRAIN BECAUSE OF THERMAL GRADIENT ACROSS TUBE

AXIAL STRAIN BECAUSE OF THERMAL GRADIENT ACROSS TUBE

Regime A and B ~~EX~~ ΔT

TUBE BUCKLING

I. IN HOOP DIRECTION, TUBE IS FLEXIBLE ENOUGH TO ACCOMMODATE THERMAL GROWTH

II. IN MERIDIONAL DIRECTION, THERMAL GROWTH = $\alpha \cdot T$

WHERE, α = MEAN COEFFICIENT OF THERMAL EXPANSION

ΔT = TEMPERATURE DIFFERENCE FROM TUBE CROWN TO JACKET COULD CAUSE BUCKLING.

FOR A SINUSOIDAL WAVE BUCKLING PATTERN $Y = A \sin \frac{\pi x}{L}$, $A = \frac{2L}{\pi} \sqrt{\alpha \Delta T}$

TEST OF SMALL ALUMINUM-JACKETED TUBE BUNDLE SUBJECTED TO $T = 1900^\circ\text{F}$

SHOWED: 1. $L = 1/4$ in. 2. $A = 0.010$

FOR NUCLEAR ENVIRONMENT, PREDICTED BY REGIME A AND B, $\Delta T_{\text{MAX}} = 1645^\circ\text{F}$

AND $A = 0.021$ in.

III. BUCKLING IS ALWAYS RADially INWARD.

WELDED CAP VERSION

FORGED-JACKET FABRICATION MILEPOSTS

S/N	FORGING RECEIPT	COMPLETE GROOVING	COMPLETE BRAZING	COMPLETE FABRICATION, WEEK OF	REMARKS
008				2-24-64	
009			2-7-64	3-2-64	
021		2-19-64	3-18-64	4-13-64	BASED ON COMPLETION AS U-TUBE CONFIGURATION
A	1-27-64	3-30-64	4-27-64	5-25-64	
B	2-17-64	4-13-64	5-9-64	6-8-64	
C	3-7-64	5-4-64	6-8-64	7-13-64	
D	3-30-64	6-8-64	7-13-64	8-17-64

NERVA PROGRAM

HYDROSTATIC TEST CONDITION HOOP STRESS

Nerva Nozzle, Steel Jacket

HYDROSTATIC TEST CONDITION, MERIDIONAL STRESS

REACTOR FIRING - STEADY STATE MERIDIONAL STRESS

REACTOR FIRING, STEADY STATE HOOP STRESS

SUMMARY OF CRITICAL CONDITIONS - STEEL JACKET NOZZLE

CONDITION	CHAMBER PRESSURE (psi)	FLG AV TEMP (°F)	M (in. /lb/in.)	Q (lb/in.)	V (lb/in.)	ULTIMATE MARGIN OF SAFETY
HYDROTEST	880	70	-800	6467	9,346	3.8
COLD FLOW	--	--	--	--	--	STRUCTURAL ANALYSIS NOT COMPLETE
SIMULATION	--	--	--	--	--	STRUCTURAL ANALYSIS NOT COMPLETE
A-2 (REACTOR)	665	-380	(P) -505 (T) $\frac{2377}{1872}$	(P) 7080 (T) $\frac{173}{7253}$	6772	2.3

NERVA PROGRAM

METHOD OF ASSEMBLY FOR BRAZING OPERATION

METHOD OF ASSEMBLY FOR BRAZING OPERATION

NOZZLE S/N 0000009

FORGED NOZZLE MANIFOLDING

S/N 8&9

S/N 21 AND ALL FUTURE FORGED NOZZLES

BASIS FOR NOZZLE CONFIGURATION SELECTION

- PRODUCIBILITY
 - YIELD
 - COSTS

- RELIABILITY
 - SIMPLICITY OF ACCEPTANCE
 - DURABILITY

KEY MILEPOSTS FOR NOZZLE CONFIGURATION SELECTION

31 JAN 1964

BRAZED VS WELDED FORGED NOZZLES

BASED ON OUTCOME OF BRAZING OF S/N 008 AND 009

15 MARCH 1964

BRAZED VS CAST NOZZLE

BASED ON OUTCOME OF HOT FIRING TESTS ON S/N 008 AND 009

30 APRIL 1964

WELDED VS CAST NOZZLE

BASED ON OUTCOME OF HOT FIRING TEST ON S/N 021

NERVA PROGRAM

NRX-A NOZZLE SCHEDULE

NRX-A	1	2	3	4
TEST DATE	15 FEB	31 JULY	31 OCT	5 JAN 1965
CAST NOZZLE S/N COMPLETION DATE	11 19 DEC	12 9 MAR	15 1 APRIL	16 15 MAY
BRAZED-FORGED NOZZLE S/N COMPLETION DATE	--	21 15 APRIL	22 31 MAY	23 14 JUNE
WELDED FORGED NOZZLE S/N COMPLETION DATE	--	21 30 APRIL	22 31 MAY	23 14 JUNE

TEST SCHEDULE, BRAZED FORGED NOZZLE

TEST	1964	J	F	M	A	M	J	J	A	S
C-6										
FORGED NOZZLE EVALUATION							2-022			
AND ACCEPTANCE							2-023			
HOT-BLEED PORT							4-08M			
INJECTOR DEVELOPMENT							4-012			
H-4										
HOT-BLEED PORT									4-09M	4-09M
FORGED NOZZLE EVALUATION				2-009		2-021			2-024	2-025
AND ACCEPTANCE										
NOZZLE ENDURANCE						3-009				
INJECTOR DEVELOPMENT					3-008

NERVA PROGRAM

TEST SCHEDULE - WELDED FORGED NOZZLE

TEST	1964	J	F	M	A	M	J	J	A	S
C-6										
FORGED NOZZLE EVALUATION								2-022		
AND ACCEPTANCE								2-023		
INJECTOR DEVELOPMENT							4-012			
H-4										
FORGED NOZZLE EVALUATION					2-021				2-024	2-025
AND ACCEPTANCE						3-021				
NOZZLE ENDURANCE										
INJECTOR DEVELOPMENT					3-008					