TID/SNA -- 1838

AEROJET NUCLEAR SYSTEMS COMPANY
SACRAMENTO, CALIFORNIA

TO: File
FROM: J. H. Ramsthaller
ENCLOSURE: (1) NERVA Program Material

DATE: 12 February 1971

Enclosure (1) represents NERVA Program material philosophy presented in Cleveland on 11 February 1971.

J. H. Ramsthaller, Acting Manager
Product Reliability & Safety Department

MASTER

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ANSC Program Position

Regarding

Component Design

vs

Materials Plan

Priorities

W. E. Campbell

J. H. Ramsthaller

Presented to SNSO

11 February 1971

MASTER

ANSC PROGRAM POSITION

ANSC PROGRAM OBJECTIVES

DESIGN LOGIC/RESTRAINTS

EVALUATION OF MATERIALS DATA FOR PROBABILISTIC DESIGN

COMPONENT DESIGN STATUS EXAMPLES

CONCLUSIONS

RECOMMENDATIONS

ANSC PROGRAM OBJECTIVES

SYSTEM DESIGN/ANALYSIS TO DEFINE REQUIREMENTS

CRITICAL COMPONENT DESIGN AND FEASIBILITY DEMONSTRATION

ENHANCE TECHNICAL EXCELLENCE OF CADRE FOR REBIRTH

MAXIMIZE DATA USEABILITY FOR REBIRTH

KEYS TO PROBABILISTIC DESIGN

DEFINED REQUIREMENTS, LOADS, ENVIRONMENTS

CONCEPT BASED ON REQUIREMENTS AND ACHIEVABLE MATERIAL PROPERTIES

DEFINED STRUCTURAL FAILURE CRITERIA

MATERIALS DATA BASED ON DEFINED FAILURE CRITERIA

STRESS DISTRIBUTIONS BASED ON CRITERIA & PART, COMPONENT OR ENGINE TESTS

THE DESIGN/DEVELOPMENT PROCESS

DESIGN/MATERIALS PLAN OPTIONS

OPTION 1 - ELABORATE MATERIALS DATA NOW

ASSUMES ENVIRONMENT DEFINED

ASSUMES FORM/PROCESS SELECTED

ASSUMES FAILURE CRITERIA KNOWN

- FMA & PROBABILISTIC MODEL
- STRUCTURAL ANALYSIS MODEL
- DESIGN ANALYSIS
- SUPPORTING ANALYSIS (THERMAL, ETC.)

TENDS TO MAP "ALL" PARAMETERS AT "ALL" ENVIRONMENTS

RESTRAINTS

AEROJET NUCLEAR SYSTEMS COMPANY

DESIGN/MATERIALS PLAN OPTIONS

OPTION 2 - DATA DEFERRED, MATCHED TO DESIGN MATURITY

MUST BE ADEQUATE TO SIZE PART

ALLOWS DESIGN TO PROCEED TO FMA/FAILURE CRITERIA

ALLOWS TESTS TO CONFIRM/DEFINE

- LOADS/ENVIRONMENTS
- MODELS/FAILURE CRITERIA

TRUNCATE PARTS ABOVE DESIGN PROPERTIES

DEFINE STATISTICAL CHARACTER FOR KNOWN ENVIR/CRITERIA

WEIGHT EFFECT OF MATERIAL TEST SAMPLE SIZE

$$\bar{S} = 100 \text{ KSI}$$

$$V_S = 7\%$$

YIELD CRITICAL

$$\text{SNP O-C-1} \quad \text{MS} = 0$$

$$N_S = 10$$

OBJECTIVES STATISTICAL MATERIALS PROGRAM

- DETERMINE A FEASIBLE DISTRIBUTION OF MATERIALS DATA FOR DESIGN ANALYSIS
- DEVELOP A DISTRIBUTION OF DATA FOR USE IN RELIABILITY ANALYSIS
- ASSURE AT SPECIFIED CONFIDENCE MATERIAL TO BE USED IN ANY ENGINE IS AS GOOD AS VALUES USED IN DESIGN

STATISTICAL ANALYSIS MATERIALS DATA FOR PROBABILISTIC DESIGN

- OBJECTIVES STATISTICAL MATERIALS PROGRAM
- VARIABLES WHICH EXIST IN MATERIALS DATA
- EXPERIENCE TO DATE ANALYZING TEST DATA
- LIMITATIONS OF ANY FINITE ANALYSIS
- EFFECT OF TIME ON ANY BODY OF STATISTICAL DATA
- NECESSITY FOR STATISTICAL ACCEPTANCE TESTING
- RECOMMENDED DATA ACQUISITION PHILOSOPHY

RECOMMENDED MATERIAL DATA ACQUISITION PROGRAM

DESIGN PHASE	PRELIMINARY SIZING	DETAIL DESIGN	COMPONENT DEVELOPMENT TESTING	COMPONENT QUALIFICATION	PRODUCTION
MATERIAL OBJECTIVES	LIMITED SCREENING DATA	DATA ON FAILURE CRITERIA DATA ON DESIGN CONFIGURA- TION	FAILURE DATA VENDOR DATA LOT-TO-LOT DATA	QUALIFIED VENDORS ACCEPTANCE PLAN TRUNCATION EFFECTS	GUARANTEE MATERIAL MEETS "R" NEEDS
VARIABLES IN DISTRIBUTION	WITHIN LOT DATA	WITHIN LOT DATA LIMITED LOT- TO-LOT DATA	WITHIN LOT DATA LOT-TO-LOT DATA VENDOR DATA TEST ERRORS	ALL FOR QUALIFIED VENDORS	ALL
RISK ASSESSMENT	HIGH K VALUE EXTREME VALUE LOT UNKNOWN FAILURE CRITERIA	HIGH VALUE LOT FAILURE CRITERIA NOT CONFIRMED	DATA FORCES REDESIGN	APPORTIONED RELIABILITY	APPORTIONED RELIABILITY

AEROJET NUCLEAR SYSTEMS COMPANY

YIELD STRENGTH
(3 HEATS - CRES 347 SHEETS)

	<u>MEAN</u>	<u>SIGMA</u>	<u>99/95 LIMIT</u>
● INITIAL DATA BY HEAT			
A	36.6	.71	33.9
B	35.8	.72	33.1
C	39.5	.64	37.1
● COMBINED ANALYSIS-TOTAL POPULATION			
ALL HEATS	37.8	2.33	13.2
● IF HEAT C CAN BE OMITTED			
A & B	36.2	1.05	25.1

ROOM TEMPERATURE
CIRCUMFERENTIAL YIELD STRENGTH
(3 FORGINGS - CRES 347)

	<u>MEAN</u>	<u>SIGMA</u>	<u>99/95 LIMIT</u>
● INITIAL DATA BY FORGING			
021	36.0	1.06	32.0
027	33.3	1.04	28.7
033	29.8	.88	26.5
● COMBINED ANALYSIS - TOTAL POPULATION			
ALL FORGINGS	33.0	3.25	0
● OMIT VENDOR DIFFERENCES			
027 & 033	31.7	2.97	1.3
● REMOVE TIME DIFFERENCES			
033 + PART 027	30.4	1.32	22.8
● OMIT OUTLIER DATA			
033 + PART 027	29.8	1.15	25.6

EFFECT METHOD OF ANALYSIS ON 99/95 POINT

- OPTIONS -
STATISTICAL ANALYSIS OF MATERIALS DATA

● TREAT ALL DATA AS SINGLE POPULATION

ASSUMES -

- NO VENDOR/LOT/HEAT DIFFERENCES
- SPECIMEN-TO-SPECIMEN VARIATIONS SAME AT ALL CONDITIONS

● ALLOW FOR VENDOR DIFFERENCES

INCLUDE VENDOR VARIATIONS IN MATERIAL DISTRIBUTION

ASSUMES -

- RANDOM VENDOR SAMPLE FROM LARGE POPULATION
- WITHIN VENDOR VARIATIONS SAME FOR ALL VENDORS

OR -

PERFORM SEPARATE ANALYSIS FOR EACH VENDOR

ASSUMES -

- NO LOT/HEAT DIFFERENCES WITHIN VENDOR

● ALLOW FOR LOT DIFFERENCES WITHIN VENDORS

INCLUDE LOT AND VENDOR VARIATION IN MATERIAL DISTRIBUTION

ASSUMES -

- RANDOM SAMPLE OF VENDORS AND LOTS WITHIN VENDORS
- LOT-TO-LOT VARIATIONS UNIFORM OVER VENDORS
- WITHIN LOT VARIATIONS UNIFORM OVER ALL LOTS OVER ALL VENDORS

OR

PERFORM SEPARATE ANALYSIS FOR EACH LOT

VARIABLES IN MATERIALS DATA

PRODUCT VARIABILITY

BASIC MATERIAL VARIABILITY

1. NON HOMOGENEITY WITHIN A LOT
2. VARIATIONS BETWEEN LOTS
3. VENDOR VARIATIONS
4. SHAPE PURCHASED IN

FABRICATION & PROCESSING

1. DESIGN EFFECTS - SHAPE, ETC.
2. PROCESSING EFFECTS - ROLLING FORGING CASTING
3. WITHIN VENDOR VARIATIONS
4. VENDOR TO VENDOR VARIATIONS

TECHNICAL ERRORS

1. NON-REPRODUCIBLE TEST CONDITIONS
2. VARIABILITY WITHIN A PIECE OF TEST EQUIPMENT
3. TEST EQUIPMENT VARIATIONS
4. OPERATOR DIFFERENCES AND ERRORS
5. MEASUREMENT AND DATA PROCESSING UNCERTAINTIES

TIME EFFECTS

1. ANY OF ABOVE COULD CHANGE WITH TIME

EFFECT OF TIME ON MATERIALS PROPERTIES

CONCLUSIONS

- IT IS NOT PRACTICAL NOR TECHNICALLY SOUND TO DEVELOP A UNIVERSAL DISTRIBUTION OF MATERIALS DATA AT ANY POINT IN A PROGRAM
- ANY DISTRIBUTION DEVELOPED SHOULD BE SPECIFIC FOR THE APPLICATION INTENDED
- ACCEPTANCE TESTS SHOULD BE DESIGNED TO ASSURE THE DISTRIBUTION USED IN RELIABILITY ANALYSIS IS OBTAINED IN EACH ENGINE
- IT IS NOT WISE TO DEVELOP EXTENSIVE MATERIALS TEST DATA EARLY IN A DESIGN EFFORT BECAUSE OF VENDOR CHANGES, DESIGN CHANGES, AND UNKNOWN ACCEPTANCE TEST PROCEDURES
- MATERIALS DATA SHOULD BE OBTAINED IN AN ORDERLY MANNER AS A PROGRAM PROGRESSES TO MEET DESIGN RELIABILITY NEEDS

WEIGHT EFFECT OF STRESS VARIABILITY

$S = 100 \text{ KSI}$

$V_S = 7\%$

YIELD CRITICAL

SNPO-C-1 $MS = 0$

$N_S = 10$

NOZZLE/PRESSURE VESSEL FLANGE

AEROJET NUCLEAR SYSTEMS COMPANY

NOZZLE DESIGN DATA REQUIREMENTS

ARMCO JACKET

FORGED TENSILE - FORWARD FLANGE, CONVERGENT

FORGED/WELDED TENSILE - AFT TORUS

THERMAL EXPANSION - TEMPERATURE RANGE

THERMAL CONDUCTIVITY - TEMPERATURE RANGE

FORGED FRACTURE TOUGHNESS - AFT TORUS

E MODULUS

FORGED STRESS CORROSION

TENSILE IRRADIATED

347 TUBES

TUBE CREEP

TUBE LOW CYCLE FATIGUE

TUBE TENSILE IRRADIATED

NOZZLE TUBE THERMAL FATIGUE

AEROJET NUCLEAR SYSTEMS COMPANY

PRESSURE VESSEL MID CYLINDER

AEROJET NUCLEAR SYSTEMS COMPANY

PRESSURE VESSEL DESIGN DATA REQUIREMENTS

7075 CYLINDER

FORGED K_{IC}

FORGED K_I

FORGED TENSILE IRRADIATED

FORGED K_{IC} IRRADIATED

FORGED STRESS CORROSION, SHORT TRANSVERSE

PRESSURE VESSEL CLOSURE BOLT

AEROJET NUCLEAR SYSTEMS COMPANY

TURBINE INLET HOUSING

AEROJET NUCLEAR SYSTEMS COMPANY

SECOND TURBINE ROTOR DISC FAILURE GOVERNING STRESS (BORE)
TITANIUM

AEROJET NUCLEAR SYSTEMS COMPANY

FRACTURE MECHANICS APPROACH TO DISC STRESSES

	1ST IMPELLER	1ST TURBINE ROTOR	2ND TURBINE ROTOR
$\frac{\text{ALLOWABLE DUTY}}{\text{CYCLE RATIO}}$	$\frac{8400}{60} = 140.0$	$\frac{1800}{60} = 30.0$	$\frac{1470}{60} = 24.5$
$\frac{\text{CRITICAL SIZE}}{\text{MAX GUARANTEED}} \text{ FLAW RATIO}$	$\frac{.980}{.048} = 20.4$	$\frac{.501}{.048} = 10.4$	$\frac{.441}{.048} = 9.2$
$\frac{* \text{FRACTURE STRENGTH}}{\text{CALCULATED STRESS}} \text{ RATIO}$	$\frac{316,000}{46,000} = 6.9$	$\frac{228,000}{46,500} = 4.9$	$\frac{226,000}{48,600} = 4.7$

* CALCULATED FRACTURE STRENGTH $> F_{TU}$; STRENGTH TRUNCATED TO F_{TY} FOR ANALYSIS

SECOND TURBINE ROTOR DISC BURST SPEED
(CONVENTIONAL DUCTILE ANALYSIS)
TITANIUM

AEROJET NUCLEAR SYSTEMS COMPANY

TURBINE BLADE FATIGUE

AEROJET NUCLEAR SYSTEMS COMPANY

PUMP ROTOR RETENTION BOLT
718

AEROJET NUCLEAR SYSTEMS COMPANY

TURBOPUMP DESIGN DATA REQUIREMENTS

310 HOUSINGS

FATIGUE

WELDED TENSILE

THERMAL EXPANSION

THERMAL CONDUCTIVITY

TITANIUM DISCS

FRACTURE TOUGHNESS

TITANIUM BLADES

FATIGUE

BEARING CAGES

HOOP TENSILE

HOOP TENSILE IRRADIATED

BARIUM ORIFICE RINGS

THERMAL EXPANSION

TENSILE

A286 TIE BOLTS

TENSILE

THERMAL EXPANSION

VALVE/ACTUATOR DESIGN DATA REQUIREMENTS

9310 GEARS

NOTCHED TENSILE

K_I

TENSILE IRRADIATED

K_{IC} IRRADIATED

BRONZE SEALS

NOTCHED TENSILE

BERYLLIUM COPPER SPRINGS

TENSILE

TENSILE IRRADIATED

K_{IC} IRRADIATED

A286 SPRINGS

DYNAMIC MODULUS

TENSILE

FEURALON CAGES

TENSILE IRRADIATED

FLEXURE IRRADIATED

TITANIUM BODY

K_I

RESTRAINTS

AEROJET NUCLEAR SYSTEMS COMPANY

CONCLUSIONS

RELATIVELY SMALL ADDITIONAL DATA REQUIREMENT FOR DESIGN TO PROCEED

ADDED DESIGN MATURITY REQUIRED TO DEFINE DATA REQUIREMENTS

TRUNCATION APPROACH AFFORDS REASONABLE DESIGN RISK

STATISTICAL DATA DEFERRAL IS PROPER

RECOMMENDATIONS

SELECT DESIGN PROPERTIES TO REACH FLAT PART OF CURVE

INTERPRETATION OF AVAILABLE DATA

TEST TO SAMPLE SIZE OF 10, WITHIN LOT ONLY

ASSESS TRUNCATION SCRAP RISK

TEST FOR FAILURE CRITERIA CHARACTERISTICS DEFINED BY ANALYSIS/TEST

TEST TO SAMPLE SIZE OF 10

TRUNCATE DEVELOPMENT PARTS TO ABOVE VALVES

STATISTICAL TEST TO FINAL FORM/ENVIRON/CRITERIA

ADJUST TRUNCATION LIMITS IF COST EFFECTIVE

ASSESS RELIABILITY

AEROJET NUCLEAR SYSTEMS COMPANY