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Subject: XE-2 Nozzle Readiness

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Enclosure: (1) XE-2 Nozzle Assembly Readiness Report

Reference: (a) Memorandum 7880:2486M to C. M. Rice from
W. A. Sutter, dated 3 July 1968

In anticipation of review requirements for the XE-2 Nozzle and Hot Gas Bleed Port, Enclosure (1) has been generated. This is a comprehensive technical document showing the readiness of the XE-2 Nozzle Assembly, and it includes fabrication history data, acceptance verification, and discussion of fabrication deviations (I.R.'s). It covers all aspects of review encountered on XE-1 Nozzle Readiness Review. This document satisfies the Nozzle Assembly Review Requirements including those stated in Reference (a).

Copies will be held on file for support of XE-2 Readiness Review if required. No distribution other than indicated is planned at this time.

Your comments are solicited.

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XE-2
NOZZLE ASSEMBLY
READINESS REPORT

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LIST OF ENCLOSURES

ENCLOSURE NO.

- (1) Memorandum 7411:0155M dated 4 April 1966, C. R. Snyder from W. R. Westmore, subj: Thermal Analysis of the Closure Plate Attachment XE-1
- (2) Report No. RN-TP-0018 dated 9 September 1966, "Acceptance Procedure, Nozzle, U-Tube, NERVA, XE-1"

I. INTRODUCTION

This report has been prepared for the purpose of providing a documentary proof that the P/N 1114263-99 is suitable for inclusion in the XE-2 engine assembly and is satisfactory for XE-2 power test within the limits and constraints specified herein. Pertinent excerpts from records and documentation related to aspects of XE-2 nozzle operation with emphasis on items unique to this P/N, and residual deviation from applicable documents with engineering disposition thereof are included to render this report as a self-contained document.

The nozzle and hot gas bleed port assembly which is intended for use on the XE-2 assembly is P/N 1114263-99, S/N 880028. It was designed and fabricated under Contract SNP-1. The nozzle was designed under Sub-Subtask 1.4.1, Para. A.(1)b. which stated "Design, modify, and refine as required on the basis of fabrication and test data feedback the hot-bleed port U-tube configuration nozzle and the bleed port assembly with bolt-on bleed port-to-nozzle joint." The nozzle was fabricated under Sub-Subtask 1.4.7, Para. B.(1)c. which stated "Complete fabrication of NRX-A4, NRX/EST, NRX/EST Backup, NRX-A6, XE-1, XE-1 Backup, XE-2, and XE-3 nozzles for end item usage".

Design differences in the XE-1 and XE-2 nozzles exist only in that the XE-2 nozzle was at one time built to NRX/EST configuration and instrumentation requirements. It has since been modified as necessary so that no configuration or operational differences exist.

II. ITEM DESCRIPTION

The article subject to this review is XE-2 nozzle assembly P/N 1114263-99, S/N 880028.

Figure 1 is a picture of the XE-2 nozzle. On the aft end may be seen the handling ring which, when attached, covers the aft closure flange. Since this nozzle was converted from NRX/EST Backup, on it may be seen unused instrumentation bosses which have been plugged to prevent leakage during operation. At the same axial

FIGURE 1

II. (Continued)

location as the bleed port are the pass-through bosses which are used for measuring chamber pressure and temperature. Those bosses with a nipple on the throat side do not pass-through but are available for pressure transducer evaluation if desired. Also on the picture, the welded attachment of the bolt coolant lines may be seen. A more detailed discussion of these items appears in Section V.

III. APPLICABLE DOCUMENTS

The article, as described in the preceding section, was designed in compliance with documents which contain a primary control over design and fabrication of XE nozzle and which are listed in Table I.

A. NDC 123 describes the basic design considerations for all components which are used in the X-engine. Many of the specific design requirements, discussed in detail later, are listed in this document.

B. NDC 117 is a spin-off of NDC 123, however, it addresses itself to nozzle and hot gas bleed port requirements only. Items from it are discussed further, later in this document. While this document is listed for XE-1 Engine, the nozzle requirements for XE-2 do not change from XE-1.

C. RN-TM-0159 discusses engine and component weights and centers of gravity. Also specified are proof loading factors and margins of safety for components.

D. B/P 1013843 describes the interface dimensions and tolerances between the nuclear subsystem and the nonnuclear components.

E. B/P 1114263 is the document showing the assembly of the hot gas bleed port to the nozzle. This is the final nozzle configuration and is the part number under which it is delivered to the Test Site.

F. B/P 1117100 is a special drawing which was made to convert the NRX/EST Backup nozzle for use on XE-2.

G. B/P 706988 is the primary nozzle assembly drawing which does not include the hot gas bleed port. This drawing describes the most critical fabrication stages

TABLE I

APPLICABLE DOCUMENTS

NDC 123	X-Engine Components, Basic Design Criteria for
NDC 117	Nozzle Assembly for the XE-1 Engine
RN-TM-0159	Basic Loads and Structural Design Criteria for the XE-1 Engine
B/P 1013843	Interface Control, XE-1, XE-2 Nuclear Sub Assy (U)
B/P 1114263	Nozzle, Nuclear Rocket Engine (U)
B/P 1117100	Nozzle, Hot Gas Port, Nuclear Rocket Engine
B/P 706988	Nozzle, Hot Gas Port, Nuclear Rocket Engine (U)
B/P 706967	Port, Hot Gas, Nozzle (U)
AGC-90006	Nozzle, U-Tube, Tube Installation and Brazing, Procedure for (U)
AGC-STD-9001	Nozzle, U-Tube, NERVA, Cleaning and Protection of
AGC-STD-9007	Cleanliness Levels, Components and Assemblies
AGC-46351	Process Specification, Fusion Welding
AGC-STD-1151	Inspection, Radiographic, Materials, Procedures for
AGC-STD-4005	Engineering Acceptance Criteria for Welds
RN-S-0338	Structural Analysis of the XE-1 Pressure Vessel Components and Assembly
Report 2275	Materials Properties Data Book
XE-2 MRL	Measurement Requirements List

III.G. (Continued)

of the nozzle beginning with the fit up of the coolant channels around the bleed port boss and including the braze procedure, final welding and machining, and hydrostatic testing.

H. B/P 706967 is the top assembly of the hot gas bleed port.

I. AGC 90006 is the procedure for installation and brazing of the coolant channels to the nozzle jacket. It describes the alloy composition and placement of the alloy. It also describes the equipment, atmosphere, and heating cycles to be used during the braze process.

J. AGC-STD-9001 describes the cleaning procedure employed on the nozzle. It describes the cleaning prior to braze as well as the final cleaning procedure.

K. AGC-STD-9007 describes the cleanliness levels used on the nozzle. In-process levels are prescribed along with final levels.

L. AGC-46351 is the welding specification used in all cases on the nozzle.

M. AGC-STD-1151 is the radiographic inspection procedure and AGC-STD-4005 is the acceptance criteria for radiographic films of weld joints.

N. RN-S-0338 is the stress analysis of the pressure vessel and nozzle. It discusses both the nuclear test conditions and the hydrostatic test condition. This report will be referred to later in this document. Whereas the title states XE-1, information contained in this document is directly applicable to XE-2.

O. Report 2275 is the Materials Properties Data Book listing design values for the materials in use on the NERVA engine. Analyses of the XE nozzle used values as listed in this book.

P. XE-2 MRL is the Measurement Requirements List for the XE-2 assembly. The nozzle was made to accommodate the instrumentation as required by that document.

IV. DESIGN REQUIREMENTS AND COMPLIANCE WITH

Listed in this section are the design requirements applicable to the XE-2 nozzle which have been taken from NDC 123 and NDC 117. Listed with the requirement is the evidence of compliance. The list of requirements is summarized in Table II.

A. ENVELOPE AND INTERFACES

Nozzle interface constraints are defined on the Interface Control Drawing 1013843. The nozzle characteristics, which are subject to interface control, all fall within the specified tolerances except two of them. One, the inside diameter of the core end flange as measured in the area between the flange face and .50 inches from the flange face is required to be 36.110/36.050. This diameter is 36.112/36.079. Two, the face of the core end flange is required to have a 32c surface finish over its entirety. At the very O.D. edge of the flange, there are some nicks in excess of the 32c surface finish. Toward the I.D., some tube end cap faces lie below the nominal surface by as much as .002 inches (Ref. I.R. 435027). Further definition of the surface finish requirement shows that a bandwidth from 0.05 to 1.10 inches inward from the O.D. is the actual area where the 32c surface finish is required. The nozzle does meet this amended criterion. The Westinghouse Astronuclear Laboratory was notified of these two deviations and has accepted them. The WANL reply is documented per TLX-2037 dated 3-10-67.

B. NOZZLE DESCRIPTION

A general nozzle description is given in Paragraph 1.2 of NDC 117. The nozzle is a convergent-divergent shape with a half-angle convergence of 45° , a half-angle divergence of 17.5° , and an exhaust-expansion ratio of 10:1. It is convectively cooled through stainless steel tubes which are supported by a stainless steel jacket. The hydrogen propellant from the pump discharge line enters the nozzle assembly through a torus inlet manifold at the exit end of the nozzle, makes a single pass flow through the tubes emerging radially from the forward end into the manifold of the attached pressure vessel. A portion of the coolant is diverted through external tubes to cool the flange and fasteners which mount the nozzle to the pressure vessel. A hot

TABLE II
XE NOZZLE DESIGN REQUIREMENTS

REQUIREMENTS	DEMONSTRATION
A. Envelope and Interfaces (NDC-117) Applicable Drawing 1013843	No deviations to XE ICD except as noted in Paragraph A, Section IV.
B. Description, Document No. NDC 117 Paragraph 1.2	Dwg. No. 1013590-19, 706988-19, 1117100-9. No deviations.
C. Handling-Capable of Post-Operative Remote Disassembly	NRX/EST
D. Position Indicator	Provided as per 706988.
E. Fluid ports: Clamp type design.	Provided as per 706988 and 706967.
F. Hot Bleed Port Insert Assy Flow Requirement	Provided as per 1114263-99, Demonstrated (Hydrotest)
G. Leak Check Cover, Provision for	Provided per Drawing 1117100.
H. Applied Loads per NDC-117, RN-TM-0159 and NDC-123, RN-S-0231	1. Analyses - Doc. No. RN-S-0338 2. Hydrotest 3. NRX/EST 4. Simulation Testing
I. Pressure Drop, 170 PSID Max	Hydrotest: Requirement Satisfied. Expected $\Delta P = 163$ PSID ($K_w = 30.01$)
J. Thermal Shock, Sudden Drop from 620 to 36°R	Not demonstrated beyond NRX/EST test conditions
K. Thermal Gradients	NRX/EST and analysis RN-S-0338
L. Cleanliness	AGC-STD-9007, Levels II and III, Requirement satisfied.
M. Markings per ASD 5215	Drawing 706988 and 1114263
N. Materials Properties	Per Data Book 2275
O. XE-2 MRL	Provided for per Drawing 1117100
P. Leakage, NDC 123, Para. 3.1.1.6	Satisfied the requirement using 4 times the spec. pressure.
Q. Nonmetals	None used.
R. Protective Treatment (Restrictions)	None used.
S. Non-Operating Conditions NDC 123 3.2.2.2(a) through (1).	The assembly is not susceptible to damage under conditions stated. (No demonstration was conducted.)

TABLE II
(Continued)

REQUIREMENTS	DEMONSTRATION
T. Service Life	Demonstrated (NRX-A5, EST)
U. Storage Life	Demonstrated (S/N 025)
V. Exposure to Reactor Exit Gases: Capability of:	
a. Nozzle wall throat/ exit - 1620/700°F	Demonstrated by chemical simulation tests to 1900/460°F without failure.
b. Bleed Port on Spacers/ BTW spacers - 1460/ 1360°F	Demonstrated by chemical simulation tests to 1760/1580°F without failure.
W. Capable to withstand Self- induced vibration.	Analyses (RN-TM-0281), NRX/EST, Chem. Sim.
X. Capable to withstand Gamma Heating	Analyses (7730:0522M) Jacket analyzed to 1500 MW (1.5) Limiting P_c to 750 psia
Y. Operate safely with design coolant flow rates	Demonstrated (Chem. Sim.)
a. Nozzle 74 lb/sec	54.6 lbs/sec
b. Bleed Port 4.66 lb/sec	2.51 lbs/sec
Z. Provide and operate at T_{IT} of 1184°R	1608°R

IV.B. (Continued)

gas bleed port is located in the convergent section of the nozzle to bleed off hot hydrogen gas for the turbine drive. These features are shown in working drawings used for nozzle fabrication. The primary applicable AGC drawings are 1114263, 1117100, 706988, 707217, 1013590, and 706967. The XE-2 nozzle does not deviate from these requirements or capability to meet same.

. C. The nozzle shall be capable of post-operative remote disassembly. All nozzles during the NRX series including the NRX/EST were remotely disassembled from their respective engines. The nozzle-pressure vessel flange is a bolted joint with sufficient clearance for easy access with remote handling equipment. The turbine inlet line and pump discharge line are attached by clamp type joints which are easily removed with remote equipment. No changes which would effect this capability were introduced.

D. POSITION INDICATOR

The nozzle is equipped with an index pin at circumferential location of engine $\theta = 0^\circ$. This is provided to prevent misalignment of the nozzle with the pressure vessel. In addition, a small, nonfunctional hole is provided on the O.D. of the nozzle-pressure vessel mating flange to provide visual position reference. These items are shown on B/P 706988.

E. FLUID PORTS

The hot gas bleed port and the nozzle inlet flanges are of clamp type design. They use a conical, metallic seal which is crushed on the edges as the mating flanges are brought together by the clamp around them. The details of these flanges may be seen on Page 4 of B/P 706988 for the inlet flange and B/P 706967 for the hot gas bleed port flange.

IV. (Continued)

F. HOT GAS BLEED PORT INSERT ASSY

The nozzle is provided with a hot gas bleed port insert. This assembly was fabricated as S/N 880202. The flow coefficient through the port is determined by water flow testing. The formula used is:

$$\dot{w} = K_w \sqrt{\Delta P \times S. G.}$$

$\dot{w}$ = flow rate in lbs/sec

K_w = flow coefficient

ΔP = pressure drop in psi

S.G. = specific gravity of
flowing fluid

The K_w of this port is 6.97. To best determine the operational pressure drop, this port may be compared to the port used on NRX/EST, which was of the same design and had a K_w of 7.03. At one point during the NRX/EST series, 5.59 lbs/sec was flowing at 92 psi pressure drop. Comparing this to the port for XE-2 shows a pressure drop of 87.2 psi at 5.4 lbs/sec flow rate. This is within the prescribed constraints.

G. LEAK CHECK COVER

A flange has been installed on the XE-2 nozzle for the mounting of a leak check cover. This will be discussed further later in the report. The flange and its installation are shown on B/P 1117100.

H. APPLIED LOADS

The nozzle assembly is required to withstand loads applied by the pressure and flow requirements of the engine, the loads due to thermal gradients, and loads as applied by other components due to weight and inertia. The nozzle shall withstand these loads either singly or in combination. The primary document describing nozzle load carrying capability is RN-S-0338, "Structural Analysis of the XE-1 Pressure Vessel Components and Assembly". This report states that the critical case is the hydrotest condition. The nozzle is hydrotested at 800 psig with water as the test

IV.H. (Continued)

medium. The maximum stress level during this test is 21,400 psi. This gives a margin of safety of +.22 which includes the 1.15 safety factor. The maximum stress during nuclear firing condition is 15,400 psi. This gives a margin of safety of +.66.

Tensile test bars taken from the forging of this nozzle showed a minimum yield strength of 26,700 psi. This condition is discussed further in Paragraph A, Section VIII. If in the stress analysis the actual yield strength of 26,700 psi is used rather than the 30,000 psi specified in Report No. 2275, a margin of safety of +.08 exists in the hydrotest condition and +.44 margin of safety exists in the nuclear firing condition.

Two basic hydro proof tests were conducted on the nozzle. The coolant channels and inlet torus were proof tested to 1150 psig, and the nozzle chamber upstream of the throat, with the hot gas bleed port installed, was proof tested to 800 psig. The internal passages of the hot gas bleed port were proof tested at 175 psid. During operation the expected differential pressure drop is 87 psid. This proof differential pressure was arrived at by applying proof loading factors and ratio of yield strength at room to operating temperatures.

A nozzle of like design was on the NRX/EST. It performed as predicted on NRX/EST with no anomalies.

A nozzle of like design was tested in chemical simulation conditions. The following table provides a direct comparison of pressures.

	<u>XE-2</u>	<u>Chemical Simulation</u>
a. Inlet	905 psia	1080 psia
b. Outlet	735 psia	913 psia
c. Chamber	561 psia	802 psia
d. Diluent Inlet	687 psia	909 psia

IV. (Continued)

I. PRESSURE DROP

The nozzle coolant circuit shall have a maximum pressure drop of 170 psid. The best method of determining operational pressure drop is to compare the XE-2 nozzle to that used on NRX/EST. From water flow tests, the following flow coefficients were established: $\text{NRX/EST} = 29.47$; $\text{XE-2} = 30.01$. At a point in the NRX/EST test, the total weight flow was 76.2 lbs/sec and the pressure drop was 165 psid. Equating these to XE-2 conditions shows a pressure drop of 163 psid.

J. THERMAL SHOCK

The nozzle shall be capable of withstanding a sudden temperature decrease from 620°R to 36°R . No demonstration of this has been performed beyond the decreases shown in the NRX, XECF, CFDTs, and chemical simulation test series.

K. THERMAL GRADIENTS

The nozzle jacket and mounting flange must be capable of withstanding the thermal gradients resulting from the combination of operating fluid temperatures and the heat generation resulting from nuclear radiation. In RN-S-0338, it states that the nozzle jacket and flange have a fatigue life of 35,000 stress cycles due to temperature differences in the flange. Additionally, the nozzle used on NRX-A6 withstood the thermal gradients which were applied in that test.

L. CLEANLINESS

Nozzle cleanliness is per the applicable level of AGC-STD-9007 as specified in AGC-STD-9001, "Nozzle, U-Tube, Cleaning and Protection of".

M. MARKING

All markings on the nozzle, i.e., part number, serial number, are as per ASD 5215.

N. MATERIALS PROPERTIES.

Materials Properties used for analysis of nozzle characteristics are as specified in Materials Properties Data Book Report 2275.

IV. (Continued)

O. XE-2 MRL

Provisioning has been made to accommodate instrumentation on the nozzle as required on the XE-2 MRL.

P. LEAKAGE - NDC 123 Paragraph 3.1.16

There is one interface connection on the nozzle assembly to which the leakage requirement is applicable. This is the joint between the hot gas bleed port and the nozzle. The joint was tested with helium at 200 psig which is 4 times the specification requirement. No bubbles were noted when leak check solution per MIL-L-25567 was applied. In addition, checking of the bolt coolant line attachments and instrumentation bosses showed that no leakage existed at these points either.

Q. NONMETALS (RESTRICTIONS)

No nonmetals are used in the nozzle assembly.

R. PROTECTIVE TREATMENT (RESTRICTIONS)

None of the nozzle components, subassemblies or assembly require protective treatment.

S. NONOPERATING CONDITIONS OF NDC 123, Paragraph 3.2.2.2^{*}(a) through (i)

The nozzle assembly, when installed in the engine assembly, is not susceptible to damage from the stated conditions. (No demonstration related to the stated conditions has been conducted.)

T. SERVICE LIFE

The nozzle shall be suitable for a service life of 1800 seconds at steady state, full power conditions. Like nozzles have been demonstrated to be capable of this requirement in three tests of the NRX series of experiments, NRX/EST, NRX/A5, and NRX/A6.

^{*} Paragraph 3.2.2.2 (a) through (i) refers principally to weather conditions.

IV. (Continued)

U. STORAGE LIFE

The nozzle shall be capable of storage for one year. Nozzle S/N 025 was held in storage for over one year. It was then subjected to all the nozzle proof and leak tests which are required for a nozzle. It passed all tests.

V. The nozzle shall operate satisfactorily when exposed to the reactor exit gases. Heat transfer analyses and NRX series experience show that the nozzle tube hot gas side wall temperature (T_{wg}) will be 1620°F just upstream of the throat and 700°F at the nozzle exit. During chemical simulation testing the throat region reached 1900°F and the aft end reached 460°F. Heat transfer analyses and NRX/EST experience show that the hot gas bleed port will reach a temperature of 1460°F over liner spacers 1360°F between liner spacers. During chemical simulation testing, a temperature of 1760°F was experienced over the spacers and 1580°F between the spacers. The nozzle operated satisfactorily during chemical simulation at the temperature quoted.

W. The nozzle shall be capable of withstanding the self-induced vibration. The nozzle exit gases are the main contributor to nozzle vibration. Since the vibration generated is random, the main consideration is at the nozzle natural frequency of 235-240 cps in the Bell (breathing) mode. Per RN-TM-0281, the nozzle is capable of withstanding $\pm 353g$ at the resonant frequency. From the XECF vibration analyses, it is expected that the XE nozzle will see less than $\pm 10.5g$. Vibrations during chemical simulation tests reached values of $\pm 15g$'s.

X. The nozzle shall be capable of withstanding the internal heat generated from nuclear radiation. An analysis of the NERVA Technology Nozzle has been made using internal heat generation rates which would exist from a reactor operating at 1500 megawatts. To add conservatism to the analysis, the stipulated heating rates were increased by 50%. These rates resulted in a maximum mean wall temperature of 1117°R and a maximum external wall temperature of 1355°R. With these metal temperatures, the limiting chamber pressure, i.e., margin of safety = 0.0, is 750 psia.

IV. (Continued)

Y. The nozzle shall operate safely at design flow rates. This requirement has been demonstrated during chemical simulation testing. Design coolant channel flow rate is 75 lbs/sec, and design diluent flow rate is 4.66 lbs/sec. While the heat fluxes to the coolant channels and hot gas bleed port liner were being over simulated, coolant flow rate was reduced. Satisfactory operation of the coolant channels was shown with coolant flow rate of 54.6 lbs/sec and of the bleed port liner was shown at 2.51 lbs/sec.

In addition, chemical simulation test data summaries shown in Tables III and IV, which have been extracted from RN-TM-0195, RN-TDI-0007 and RN-S-0366, and have been provided to further illustrate the ability of the nozzle/hot gas bleed port insert assembly to operate at XE-2 conditions.

Z. The hot gas bleed port shall provide and operate with gas flowing through it at 1184°R. During chemical simulation testing, the port operated with gas at temperatures as high as 1608°R.

V. DESIGN CHANGES WITH REGARD TO NRX/EST

Table V below is a listing of the introduced design changes with respect to NRX/EST Nozzle assembly.

The NRX/EST assembly was chosen as basis for comparison, because as of this writing this was the last and the only hot bleed port nozzle exposed to nuclear environment. However, design changes, if any, with respect to XE-1 nozzle assembly are also shown.

TABLE III
SUMMARY OF NOZZLE HEAT TRANSFER TEST DATA

TEST NO.	DURATION (SEC)	STEADY STATE DURATION (SEC)	CHAMBER PRESSURE (PSIA)	MIXTURE RATIO		NOZZLE COOLANT FLOW (LB/SEC)	MAXIMUM PREDICTED HOT-GAS-SIDE TUBE WALL TEMP (°F)
				NOMINAL	BETWEEN BAFFLES		
001	15.1	7.8	674	4.7	5.8	72.9	1648
002	1.7	0	437	1.2	1.5	75.0	----
003	6.5	0	721	3.6	4.5	77.1	----
004	3.5	0	661	2.8	3.5	74.0	----
005	5.8	0	645	5.0	6.2	56.7	----
006	20.8	13.3	736	4.85	6.0	71.3	1745
007	20.5	11.5	789	4.66	5.8	72.8	1806
008	20.8	12.0	801	4.63	5.7	54.6	1900
009	1.3	0	---	----	---	----	----
010	20.4	11.5	801	4.63	5.7	43.2	1997

TABLE IV

HOT BLEED PORT CHEMICAL TEST EXPERIENCE USING CRES 347 LINER MATERIAL

TCA S/N	TEST NO.	P _C (PSIA)	MR	W _{H.G.} (LB/SEC)	W _{DIL} (LB/SEC, EXCLUDING BYPASS)	% DIL BYPASS	DIL ΔP (PSI)	TURBINE INLET TEMP (°R)	BLEED PORT LINER MAX WALL TEMP (°R)			
									COMPUTER PREDICTED		MEAS. BY BRAZE ALLOYS	
									OVER SPACERS	BETWEEN SPACERS	OVER SPACERS	BETWEEN SPACERS
013	010	563	5.17	5.06	3.40	0	101	1597	2156	1968	-	2035
013	013	567	5.19	5.87	2.51	26.4	31	1608	2311	2202	-	-
021	006	645	4.72	6.40	4.53	14.1	72	1235	2152	1920	>2157	<1960
021	007	638	4.72	5.55	4.72	14.1	93	1157	2101	1851	-	-
021	010	652	4.59	5.97	4.23	14.1	62	1387	2184	1978	>2157	<1960
027	001	679	4.71	6.44	3.47*	8.3	54	1590	2232	2047	-	-
027	006	736	4.85	5.51	5.72	8.3	60	1250	2053	1790	-	-
027	007	789	4.66	5.64	5.65	8.3	52	1270	2053	1792	-	-
027	008	801	4.63	4.76	6.02	8.3	60	1280	1970	1709	-	-
027	010	801	4.63	4.85	5.52	8.3	62	1550	1997	1735	-	-
XE DESIGN (4090°R T _c)		563	-	1.60	4.61	14.4	90	1140	1921	1723	-	-

* DILUENT FLOW WAS RESTRICTED ON THIS TEST DUE TO ICE FORMING IN THE DILUENT MIXER UPSTREAM OF THE HOT BLEED PORT DILUENT INLET.

TABLE V
DESIGN MODIFICATIONS OF XE-2 NOZZLE ASSEMBLY
WITH RESPECT TO NRX/EST NOZZLE

- A. Bolt Coolant Circuit (No change with respect to XE-1)
- B. Coolant holes around Bleed Port (No change with respect to XE-1)
- C. Bleed Port to Nozzle Seal (No change with respect to XE-1)
- D. Aft Closure Flange (No change with respect to XE-1)
- E. Instrumentation (With respect to XE-1, as per XE-2 MRL)

A. BOLT COOLANT CIRCUIT

For the NRX/EST nozzle, the design bolt coolant flow rate was raised to 5.00 lbs/sec. This was done to reduce coolant channel pressure drop, however, the pressure drop was not so high as to cause a problem. In the XE nozzle assemblies, the design bolt coolant flow rate was reduced to 3.00 lbs/sec, diverting the difference of 2.00 lbs/sec through the coolant channels. To accomplish this, the flow controlling orifice diameter was reduced from .367 inch diameter to .320 inch diameter. To provide a more accurate bolt coolant flow measurement, the venturi throat diameter was reduced from .450 inch to .300 inch. The NRX/EST also had a bypass circuit in which some of the bolt coolant was allowed to bypass the bolts and go directly to the reflector inlet plenum. With reduced bolt coolant flow by 40%, this bypass circuit became superfluous and has been deleted. One other design change not affecting flow rate, provided for welded attachment of the bolt coolant lines rather than using threaded fittings. These design changes are reflected on B/P 1117100.

V. (Continued)

B. COOLANT DROOL HOLES AROUND BLEED PORT

To provide for greater structural integrity, the thickness of the coolant channel end caps at the hot gas bleed port bore was increased. .020 inch diameter holes through the tube crown adjacent to the end caps were drilled all around the port of the NRX/EST nozzle. This is shown in Figure 2. These holes achieve two purposes. They breakup the possibly stagnant pool in the right-angle corner to assure coolant flow at the corner, and they provide a film coolant of the end cap. The amount of flow exiting at this point is less than .1% of total flow. To ensure that the increased thickness of the end caps will not produce overheating on the downstream side of the port using hot gas flow direction for reference, these drool holes were drilled at an angle through the end cap rather than adjacent to it. The upstream side was not changed. Both designs are shown in Figure 2, and the nozzle conforms to the blueprint requirements.

C. BLEED PORT TO NOZZLE SEAL

The capability of the seal between the hot gas bleed port and the nozzle used on the NRX/EST to perform effectively was determined to be marginal. It was an E-seal per P/N 1115237. A test program to find and prove a more effective seal was undertaken. This program and its results are documented in RN-TM-0408. The seal selected was the Omega seal per P/N 1114180-25. Five seal designs were selected for test, and four designs were actually tested as stated in RN-TM-0408. The test results for the E-seal and Omega seal are shown in Figure 3. The seal test device was pressurized to 800 psig with helium and the pressure loss in 5 minutes was determined. As shown, the Omega seal is clearly superior. B/P 1114263 depicts the design change to the Omega seal.

NRO

**COOLANT HOLES AROUND BLEED PORT
(DOWNSTREAM OF PORT ONLY)**

.070/.080 PRIOR TO MACHINING
.063/.074 AFTER MACHINING
EST

.100/.110 PRIOR TO MACHINING
.084/.095 AFTER MACHINING
XE

SUBJECT TO LAYUP TOLERANCES

SEAL BETWEEN HOT GAS BLEED PORT AND NOZZLE

CROSS-SECTION
OF 1115237
NRX/EST

CROSS SECTION
OF 1114180-25
XE

PRESSURE DECAY IN 5 MIN. FROM 800 PSIG USING HELIUM

S/N	CYCLES	DECAY (PSI)
17	1	115
	2	98
	3	80
18	1	20
	2	17
	3	14

S/N	CYCLES	DECAY (PSI)
374	1	3
	2	3
	3	5
375	1	4
	2	5
	3	3
378	1	13
	2	5
	3	3
*380	1	2
	2	6
	3	11
** 383	1	19

*USED SEAL

**INTERFERENCE IN SEAL TESTER

V. (Continued)

D. AFT CLOSURE FLANGE

Per NDC-117, Paragraph 3.1.2.6, the nozzle assembly shall include provision for installation of a cover over the exit cone for the purpose of leak checking. Additional material was welded to the nozzle aft end, and from this, a flange of clamp type design, suitable for remote installation of the cover, was machined. Included in this report as Enclosure 1 are the results of an analysis to determine the flange temperature during engine operation. It should be noted that this flange is non-operational in the sense that it is not used during engine operation but is used only during leak test.

E. INSTRUMENTATION

The nozzle design has been altered to accommodate instrumentation as required on the XE-2 MRL.

VI. SUITABILITY EVIDENCE DATA

Following the completion of manufacturing processes, the nozzle is subjected to a series of acceptance tests designed to show that it is suitable for end item useage. This procedure is described in RN-TP-0018, "Acceptance Procedure, Nozzle, U-Tube, NERVA, XE-1". While this document refers to XE-1, the same procedures apply to XE-2 without deviation. A copy of RN-TP-0018 is included in this document as Enclosure 2, however, its highlights are reviewed here as they apply to the XE-2 nozzle.

A. FLOW COEFFICIENT DETERMINATION

This item has been covered in Paragraph I of Section IV.B.

B. INDIVIDUAL COOLANT CHANNEL FLOW.

In addition to measuring the flow rate through each tube so that it may be compared with the mean flow rate through the tubes, this test verifies that all tubes are clear of blockage. At one time, several tubes of this nozzle were plugged

VI.B. (Continued)

with O-ring material. It was this test during which the plugged condition was detected. The description of this incident is given in the narrative foreword of the End Item Report. The final results of the individual tube flow test are shown in Figure 4 for the XE-2 nozzle. The final results of the NRX/EST nozzle individual tube flow test are shown in Figure 5 for comparison. As may be seen from these figures, no low-side deviation from the mean for the XE-2 nozzle goes lower than the worst condition on the NRX/EST nozzle. During the heat transfer margin of safety testing in which incipient tube failure was deliberately induced, it was not the low-flow tubes intersected by the hot gas bleed port in which failure occurred.

C. RADIOGRAPHIC INSPECTION

An x-ray inspection is performed to verify the results of the individual tube flow that all channels are clear. The x-ray is especially effective in detecting metallic chips which may have been inadvertently introduced into the coolant channels during final machining. Final x-ray inspection shows the nozzle coolant passages to be clear as shown on page 1 of I.R. 436111.

D. COOLANT CHANNEL PROOF AND LEAK

A series of three proof and leak tests is performed on the coolant channels. A gaseous nitrogen test is made following leak repair to verify that the welded and brazed joints are leaktight. This is done at a proof pressure of 200 psig and a leak pressure of 100 psig. A high pressure water test is then conducted to verify the structural integrity of the coolant circuit. The proof pressure for this test is 1150 psig and the leak pressure is 860 psig.

After all of the tests described below are completed, a final helium leak test is made on the coolant circuit. This test is done at a proof pressure of 200 psig and a leak pressure of 100 psig. Its purpose is to verify that, after all other operations are complete, the coolant circuit has no leaks. The XE-2 Nozzle has satisfactorily completed all these tests.

XE-2
NOZZLE

FIG 4

NRX / EST
NOZZLE

FIG 5

VI. (Continued)

E. CROSS-SECTIONAL AREA TEST

The nozzle coolant channels are filled with water to which has been added a wetting agent. The solution is drained from the channels over measured lengths and the volume is measured. From these values, the cross-sectional areas at selected stations along the tube length are computed. The cross-sectional areas of the XE-2 nozzle are shown in Figure 6. This graph may be compared to the NRX/EST nozzle for which the cross-sectional areas are shown in Figure 7.

As this test measures only the total cross-sectional area and not the possible deviation of one tube, the maximum credible single tube deviation has been calculated to be 11.7%. This deviation was calculated by allowing the channel to ride out of the groove to the maximum tolerance and allowing the grooves to separate to the maximum tolerance. This flow area increase would allow an increase in hot gas side tube wall temperature of 60°F from nominal design conditions. In obtaining the 60°F temperature increase, it was assumed that no flow redistribution would occur. There would, however, be some flow increase in the enlarged tube due to the impedance reduction.

F. CHAMBER PROOF AND LEAK TEST

The nozzle is assembled to a pressure vessel simulator on the core end and a plug is installed in the throat. The assembly is then proof and leak tested with water at 800 and 600 psig respectively. The purpose of this test is to show the structural integrity of the nozzle jacket and hot gas bleed port attachment.

The assembly is then dehydrated and proof and leak tested with helium at 200 and 100 psig respectively. This is done to show that after the structural proof test the nozzle to hot gas bleed port seal continues to perform without leakage. The XE-2 nozzle has successfully completed all these tests.

359-1110
10X10 TO THE 1/2 INCH
RECEIVED 1958-11-17

FIG 6

10X10 TO THE 11 INCH 359-111G

FIG 7

VI. (Continued)

G. Following the successful completion of all nozzle manufacturing processes including the aforementioned acceptance tests, final cleaning is performed. The cleaning procedure is per AGC-STD-9001C, Methods 6, 7, and 8 to the level of AGC-STD-9007 required. AGC-STD-9007 defines cleanliness levels and the methods of inspection to determine that they are met. The XE-2 nozzle has been accepted to the required cleanliness levels and packaged per RN-DR-0115 to preserve the cleanliness.

VII. MODES OF FAILURE ANALYSIS

A. LOSS OF COOLANT FLOW

It has been predicted and verified that the operational integrity of the coolant channels could be compromised if the channels' wall temperature exceeds 2000°F at the location of maximum thermal loads (throat region). One reason why the coolant channels hot gas side wall temperature may exceed the design value of 1660°F is the loss of coolant. To preclude failure, 1900°F was chosen as the limiting tube wall temperature which established a 100°F safety margin under emergency conditions. As it can be seen from Table III, the capability to operate the nozzle at tube wall temperature of 1900°F has been demonstrated only up to 12.0 second of steady state duration. To ensure that the nozzle is not exposed to conditions beyond those demonstrated, 5 second limit duration at tube wall temperature of 1900°F has been imposed. Analog computations indicate that the 5 second limit is a reasonable reaction time to retreat from the engine operating parameter which were the cause of the tube wall temperature rise to 1900°F. This time limit also allows for manual manipulation of controls if the automatic system fails to respond to the signal to do so. Figure 8 is an analog trace of coolant low availability as a function of time during emergency shutdown initiated during nominal operating conditions. On the same plot, for comparison purpose the coolant flow required for maintaining wall temperature at 1900°F and 2000°F is also shown. As it can be seen the imposed limits can be maintained.

NOZZLE FLOW RATIO DURING EMERGENCY SHUTDOWN

FIG 8

VII.A. (Continued)

Minimum coolant flow required at other combinations of chamber temperatures and pressures are shown in Figure 9. Anticipating the possibility of utilization of gaseous hydrogen for emergency cooling, requirements for gaseous hydrogen to maintain the wall temperature at 1900°F are also shown.

Figure 10 relates the same information, but the coolant flow requirements are expressed as ratios of coolant flow rate to the reactor exit flow rate.

Figure 11 shows jacket structural limits and the tube wall temperature limit superimposed on XE nozzle operating map. The nominal operating point has been shown to indicate the wide margin of safe conduct available.

B. LOW CYCLE FATIGUE

During the heat transfer margin of safety testing, the tube wall temperature exceeded 1660°F (nominal design value) three times prior to tube failure at 2000°F plus (see Table III). In addition, five tests were terminated prior to reaching a steady state because of triggered combustion instability. Because of the high energy release during the unstable combustion, it is reasonable to assume that the tube wall temperatures were in the realm of 1900°F during five of such tests. On this basis, it has been demonstrated that the nozzle possesses a minimum restart capability of at least eight times. Related analyses indicate that restarts should be limited to less than fifteen. In nuclear environment, the NRX-A3 nozzle experienced scram operation from full power, and while tube wall temperature of 1900°F apparently was not induced, the nozzle performed successfully on subsequent runs.

C. TUBE BLOCKAGE

If the flow through an individual tube is impeded by some obstruction so that its flow drops below the minimum allowable to cause a temperature of 2000°F , a minor tube failure would be expected. To preclude this type of incident, the tests of Section VI, Paragraph B and C are performed. These tests have shown that tube blockage does not exist in the XE-2 nozzle.

X-E COOLANT FLOW REQUIRED FOR
FOR 1900°F MAXIMUM WALL TEMPERATURE

$$T_{IN} = 50^{\circ}R$$
$$T_{IN} = 540^{\circ}R$$

MINIMUM $\dot{W}_C/\dot{W}_T$ TOTAL AS A FUNCTION OF
CHAMBER TEMPERATURE AND PRESSURE

— COOLANT FLOW TORUS TEMP IN = 540°R
- - - COOLANT FLOW TORUS TEMP IN = 50°R

XE NOZZLE STEADY-STATE OPERATING MAP

FIG. 11

VII. (Continued)

D. NUCLEAR OVERHEATING

As stated in Paragraph X. of Section IV., the nozzle has been analytically verified to be suitable to 1500 MW power at 750 psia chamber pressure. If chamber pressure does not reach 750 psia, higher power could be withstood.

E. OVERPRESSURIZATION

The results of an overpressurization failure would be serious. The limiting design values are therefore considerably above the nominal operating values. Following are the limiting and nominal operating values for various portions of the nozzle system.

1.	Chamber Pressure	750 psia tolerable	561 psia design
2.	Inlet Torus	1790 psia limit	905 psia design
3.	Tube Inlet	1250 psia limit	905 psia design
4.	Differential Pressure across Core End Cylinder	350 psid limit	175 psia design

The limiting pressure values assume that the material temperature is at the value it would be under engine nominal design conditions. The chamber pressure maximum is at material temperatures resulting from operation at 1500 MW power.

E. VIBRATION

Per RN-TM-0281, the nozzle is capable of withstanding ± 353 g's at nozzle resonant frequency of 235-240 cps. Per the vibration analysis of the XECF test article, the maximum expected vibration level is ± 10.5 g's.

VIII. I.R.'s DISPOSITIONED "ACCEPT AS IS"

In-process inspections resulted in QC generated Inspection Rejection Reports identifying deviations from print or specification. Residual conditions which were not restored to print or specification requirements, and which were subsequently bought-off on the basis of engineering evaluations are described below.

A. LOW YIELD STRENGTH - Reference I. R. 283220, SDAR 12250

The results of the test bars taken from this nozzle are listed in Table VI. From this it may be seen that the minimum yield strength is 26700 psi. This item has been discussed in Paragraph H. of Section IV. It may be seen that, using the 26,700 psi yield strength, positive margins of safety are maintained.

B. IMPERFECT WELD ON BLEED PORT BOSS - Reference I. R. 271059

During the machining of the bleed port boss, it was shown that adequate material had not been supplied to make the boss. A ring was welded to the face of the boss. On x-ray inspection, several areas of nonfusion and less dense inclusions were noted. These were accepted with the concurrence of the NERVA Division Stress Section. Subsequent high pressure proof test per RN-TP-0018 showed the weld to be satisfactory.

C. MACHINED THROAT OVERSIZE - Reference I. R. 292414

During jacket machining the I.D. of the throat was made 9.335 inch. Drawing callout is 9.310/9.330 inch. As may be seen from Figures 6 and 7, the actual throat coolant flow area of the XE-2 nozzle is .4 square inch smaller than the NRX/EST nozzle. This leads to a conclusion that the coolant channels were properly seated.

D. BYPASS SLOTS OVERSIZE - Reference I.R. 276268

Three of the coolant bypass slots discharging flow into the bleed port bypass manifold are machined oversize .003/.008 inch. Any change in coolant flow due to area increase would be beneficial because of reduced pressure drop.

TABLE VI

XE-2 NOZZLE MECHANICAL PROPERTIES

<u>PULLED AT VENDOR</u>	<u>ULTIMATE STRENGTH PSI</u>	<u>YIELD STRENGTH PSI</u>	<u>ELONGATION %</u>
Forward End	77900	28800	50
	76200	27500	51
Aft End	80700	31900	46
	80000	33600	49
<u>PULLED AT AGC</u>			
Forward End	75000	26700	56
	76000	28700	56
Aft End	79000	31200	44
	79800	30800	47

VIII. (Continued)

E. DEVIATION FROM BRAZE SPECIFICATION - Reference SDAR's 30014 and 30019

Due to installation difficulties with the coolant channels, some of the braze foil around the shims was replaced with powdered alloy. The nozzle tubes have passed all proof and leak tests. The same condition also existed on Development Nozzle S/N 880027 which was used on heat transfer margin of safety chemical testing. Additional data on this condition is available in confidential letter 7456:L2604, dated 22 November 1965.

F. UNDERSIZE BORE IN BLEED PORT BOSS - Reference SDAR's 30037 and 30038

If the bore, into which the hot gas bleed port is inserted, had been bored to the required size, the adjacent tubes would have been cut. The diameter required was 6.177/6.179 inch. The diameter achieved was 6.1565 inch. Subsequent nozzles were redesigned for a port bore of 6.155/6.157 inch. The hot gas bleed port was redesigned to be compatible. The length of the step in the bore was also changed to compensate for the smaller bore diameter. The functionality of the assembly has not been affected.

G. OVERSIZE NOZZLE COOLANT INLET SEAL DIAMETER - Reference SDAR 30060

The diameter at the sealing corner was machined to 6.092 inches. Blueprint callout is 6.087/6.091 inch. A special test program was conducted to determine the acceptability of conditions noted as specified on the SDAR. The closure tool was machined undersize to set up a worst condition case. Using helium as the test medium, three tests were conducted using three separate conoseals. No leakage was detected.

H. OVERSIZE BOLT COOLANT FEED HOLES - Reference SDAR 30060

Two bolt coolant feed holes are oversize .001 inch over their full length. One hole is oversize .002 inch over .250 inch length. One hole is .017 inch oversize over .125 inch length. These discrepancies will not adversely effect the bolt coolant flow.

VIII. (Continued)

I. MISLOCATED BOLT COOLANT HOLE - Reference SDAR 30060

One bolt coolant feed hole is mislocated .066 inch. However, it makes full intersection with the mating hole as required.

J. OVERSIZE BOLT COOLANT BYPASS HOLES - Reference SDAR 30060

The bolt coolant bypass holes as required for NRX/EST backup are oversize and tapered to .090 inch. These holes no longer being required have been plugged during the rework of this nozzle to XE configuration.

K. MISALIGNED TORUS HALVES - Reference I. R. 289122

The torus halves were not properly aligned prior to welding. The torus was cycled to proof pressure of 1150 psig 10 times for acceptance test of this condition.

L. INSUFFICIENT WELD OF TORUS TO NOZZLE - Reference I.R.'s 289122 & 295270

The weld of the upper torus half to the nozzle is 75% full. Proof test of Paragraph K. is applicable to this condition also. In addition, analysis by the stress section shows a margin of safety greater than +5.0 for this condition.

M. MISLOCATED DROOL HOLES - Reference I.R. 451727

Two of the .018/.022 inch diameter drool holes are further upstream by .014 and .030 inch than blueprint requirement. The film cooling effect from these holes will keep the tubes and end caps at a satisfactory temperature.

N. OVERSIZE BLEED PORT SEAL GROOVE - Reference I.R. 435034

The outside diameter of the seal groove of the hot gas bleed port to nozzle seal measures 7.003/7.012 inch. The drawing requirement is 7.000/7.006 inch. No leakage was detectable during leak tests of Paragraph F. of Section VI. All other items of Reference I.R. have been reworked to blueprint.

VIII. (CONTINUED)

O. LOOSE STUDS - Reference I.R. 440514

To accomplish the rework of the bleed port boss referenced in previous paragraph, the keensert studs which had been installed were removed. After replacement, 13 of the 16 studs were observed to wiggle up to .030 T.I.R. and .020 in rotation. Stress analysis reported in Memorandum 7730:0663M showed this condition to be acceptable. This report substantiates the successful hydrotesting to 800 psig with no leakage or evidence of overloading.

P. LACK OF BRAZE FILLET IN HOT GAS BLEED PORT - Reference I.R. 428018

Radiographic inspection revealed lack of braze fillet over a $5/8$ inch length of the braze joint between the liner and spacers of the hot gas bleed port. A similar but more extensive condition, approximately $1\frac{1}{4}$ inch long, existed on the port used in the NRX/EST. Also, the port was tested at a pressure drop of 175 psid whereas a pressure of 87 psid is expected in the XE-2. Acceptance of this condition was coordinated with the Stress section.

R. GAS HOLES IN WELD - Reference I.R. 428055

Four round gas holes, .090/.105 inch diameter, exist in the weld of the aft cover flange to the nozzle. Stress analysis reported in Memorandum 7421:0327M shows a margin of safety for this joint greater than +2.0. The Stress section concurs with the acceptance of this condition.

S. DENTS IN AFT CLOSURE FLANGE - Reference I.R. 451729

Two dents, .010 inch deep, occur on the inboard face of the aft closure flange. They do not occur in an area which is used for clamping or sealing and are, therefore, not detrimental.

T. ICD DEVIATIONS - Reference I.R. 435027

These items are discussed in Paragraph A. of Section IV. WANL TLX-2037, dated 10 March 1967 concurs with acceptance of discrepancies.

VIII. (Continued)

U. TUBE DENTS - Reference I.R.'s 276098, 289451, 296919, 440514, 440599, and 451730

The referenced I.R.'s callout the dents in the coolant channels of the XE-2 nozzle. Some of the dents are listed on more than one I.R. A summary of the coolant channel dents is given in Table VII.

TABLE VII
COOLANT CHANNEL DENTS

TUBE NO.	LOCATION	SIZE*	RADIUS	END
7	18" from Throat	Small	.03"	Forward
8	18" from Throat	Small	.03"	Forward
49	5.5" from Flange	Medium	.015"	Forward
72	1.0" from Flange	Small	.010"	Forward
85	2.0" from Flange	Scratch	.001 deep x .03 long	Forward
129	8.0" from Flange	Small	.002"	Forward
131	3.5" from Flange	Small	.005"	Forward
6 - 10	5.0" from Throat	Small	.03"	Aft
6 - 10	6.0" from Throat	Small	.03"	Aft
102-119	10.0" from Throat	Small & Medium	.03" - .12"	Aft
103-107	10.0" from Throat	Small	.03"	Aft
104-107	9.0" from Throat	Small	.03"	Aft
105-109	19.0" from Throat	Medium	.03"	Aft
141-144	16.0" from Throat	Medium	.03"	Aft
145-147	3.0" from Flange	Large Flats	Too large to measure.	Aft
151	6.0" from Throat	Small	.03"	Aft
170-172	3.0" from Flange	Large Flats	Too large to measure.	Aft
170-173	23" from Throat	Medium	.03"	Aft

All nozzle coolant channel deformations are recorded on Inspection Report whether they fall within blueprint allowable requirements or not. The primary criterion which is violated by the listed dents is that of bottom radius which is required to be .06 minimum to be acceptable. This requirement results from the thought that sharper radii would impose a discontinuity bending stress. Subsequent analysis by Engineering Stress Section as documented in Memorandum 7730:M666, dated 11 September 1967 indicates that thin-wall tubing is not susceptible to this type of stress. The primary reason to limit the dent size and establish acceptance criteria is to establish manufacturing standards for guidance and to enhance the visual appearance of the Nozzle Assembly.

VIII. (Continued)

As may be seen from the individual coolant flow chart (Figure 4) no noticeable flow reduction results from these discrepancies. It should be pointed out that the thermocouple pass-throughs cause a percentage flow area reduction greater than any of these dents.

The following tubes have .005/.015 protrusions with .15 radius at .25" from core end flange:

70, 71, 74, 75, 78, 81, 83, 84, 85, 87, 89,
90, 91, 92, 96, 103, 106, 129, 131, and 151

These tube protrusions resulted from improper installation of the tube proof and leak tool. Based on the subsequent proof test, the Engineering Stress Section recommended acceptance of the condition without rework in Memorandum 7730:M665, dated 11 September 1967.

*Sizes: Small - .125 max long by .030 max deep.
 Medium - .125 to .250 long by .030 to .080 deep.
 Large - .250 to .500 max long by .080 to .125 max deep.

V. SEAL GROOVE PITS - Reference I. R. 437771

During final machining of the seal groove in the nozzle bleed port boss, several small pits were opened in the material. These pits were in the area of the boss sleeve to nozzle weld. They were within weld acceptance criteria, but those in the seal contact region were marginal in sealing capability. Those not in the region of seal toe contact were accepted on the basis that the helium leak test showed no indication of leakage. Those in the area of the seal toe were weld filled, and the seal groove was restored to blueprint callout.

W. WELD BUILDUP OF ACCELEROMETER BLOCK - Reference I.R. 451729

On final inspection, rust was noted in a threaded hole of an accelerometer mounting block which is attached to the nozzle torus. The foreign material in the hole was removed by drilling and the hole was weld filled. The hole was drilled and tapped and the block was restored to blueprint dimensions.

VIII. (Continued)

X. SEAL WELD AT AFT FLANGE - Reference I.R. 437338

At the time that this nozzle was to be used as the NRX/EST, nine holes were drilled and tapped in the aft flange for attachment of the handling ring. As this area becomes a seal surface in the XE configuration, these holes were plugged with threaded stock and welded to establish a continuous surface. During final machining of the surface, the weld was machined away. The plugs were rewelded and the surface finish was restored.

Y. PLUG WELD OF END CAPS - Reference I. R. 436111

As previously noted, some tubes in this nozzle at one time were plugged. In the plug removal process, holes were drilled in the tube end caps to gain access to the plugged zones. After completion of removal of foreign particles, these holes were plug welded, and, on the core end, the surface finish was re-established. The tubes were then proof tested.

IX. CONCLUSIONS

Design differences in the XE-1 and XE-2 nozzles exist only in that the XE-2 nozzle was at one time built to NRX/EST configuration and instrumentation requirements. It has since been modified as necessary so that no configuration or operational differences exist.

On the basis of evidence presented, it is concluded that the nozzle P/N 1114263-99, S/N 880028 has met the criteria necessary for acceptance and as such will perform satisfactorily, as predicted to satisfy the operational requirements of the XE-2 engine.

INTER-OFFICE MEMO

AEROJET-GENERAL CORPORATION

TO: C. R. Snyder
FROM: W. R. Westmore
SUBJECT: Thermal Analysis of the Closure Plate Attachment XE-1

DATE 4 April 1966
7411:0155M;WRW:bg
Ext.8274;Bldg.2019A2

DISTRIBUTION H. J. Bronner, L. B. Claassen, G. S. Kaveney, E. V. Krivanic,
J. R. Lucier, J. Nevenzel, I. L. Odgers, K. Sato, W. A. Sutter,
E. A. Thomas, J. L. Watkins, File

Reference: (a) Goethert, B. H., Base Heating Problems of Missiles and
Space Vehicles", American Rocket Society, Missile and
Space Vehicle Testing Conference, March 13-16, 1961.
(b) McAdams, W. H. Heat Transmission, New York, McGraw-Hill,
1954.

Enclosure: (1) Closure Plate Attachment XE-1
(2) Closure Plate Attachment, Modified Design

SUMMARY

A two-dimensional, steady state thermal analysis was performed on the closure plate attachment of XE-1. The attachment is located on the exit plane of the nozzle.

METHOD OF ANALYSIS

The attachment was coded for the 2783 network generator and thermal analyzer program. Figure 1 shows the results of the thermal analysis on the first design of the attachment. This analysis assumed the outside of the attachment was an adiabatic surface. The inside was assumed to be heated by thermal radiation from the plume. Cooling was assumed to be by conduction through the welds only. No contact between the attachment and the nozzle was assumed.

Figure 2 shows the results of the analysis on the modified attachment. This attachment is welded such that total contact between the attachment and nozzle is assured. Thermal radiation to the engine compartment was assumed in this analysis. Due to reduced pressure in the engine compartment the nozzle exhaust is underexpanded and expands about 10° upon exiting from the nozzle. This expansion is not enough for direct impingement on the attachment. A paper on base heating problems by B. H. Goethert (Reference (a)) states that base heating caused by recirculation of hot exhaust gases for single nozzle configurations is, in general, relatively insignificant. In addition interaction between exhaust gases and the surrounding which causes recirculation decreases due to the low pressure of the engine compartment. As a result, the alignment chart in Figure 7-9 of Reference (b) was used to determine a natural convection film coefficient of the recirculating gases for heating the inside of the attachment.

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The modified attachment analysis also accounted for convection cooling to the passages between the manifold and nozzle tubes.

RESULTS AND CONCLUSIONS

Maximum temperature in the profile of Figure 1 is 1065°R while 716°R is the maximum temperature in Figure 2. The profile of Figure 1 is based on conservative estimates of cooling and thermal radiation heating of the attachment. These temperatures should be considered as being maximum. Temperatures in Figure 2 should be considered as being minimum since more cooling of the attachment was accounted for. In addition the estimate of natural convection heating may be low.

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CLOSURE PLATE ATTACHMENT XE-1

FIGURE 1

CLOSURE PLATE ATTACHMENT XE-1
MODIFIED DESIGN

NOTE :

1. ALL TEMPS °R
2. STEADY STATE
3. DOUBLE HEAT GENERATION
RATES
4. SCALE 2:1
- 5.

FIGURE 2

ACCEPTANCE PROCEDURE
NOZZLE, U-TUBE, NERVA
XE-1

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AEROJET-GENERAL CORPORATION

REON

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I. INTRODUCTION

The XE-1 Nozzle Acceptance Test Procedure outlines the procedures established to demonstrate that the candidate nozzle assembly (S/N 330030) is acceptable for use in the XE-1 test program at NRDS.

Chemical simulation test of development nozzle S/N 021 (P/N 707270-9), and nuclear tests of the NRX-EST nozzle (S/N 026, P/N 706983-9) established acceptability of this configuration. The candidate nozzle is identical to the NRX-EST nozzle, except for instrumentation changes and the addition of a V-band flange to the exit plane. The NRX-EST nozzle successfully withstood nuclear testing, and S/N 021 nozzle was chemically tested successfully to simulate nuclear conditions.

Static proof, leak and water flow tests, cross sectional area measurements, radiographic inspection, and cleaning are performed on the candidate nozzle, to demonstrate the nozzle has been correctly fabricated, and to provide assurance the nozzle will be capable of withstanding, without damage, the pressure loads imposed during the XE-1 test program. The tests have also demonstrated the nozzle coolant flow rate and pressure drop will be within the specified limits.

II. NOZZLE DESCRIPTION

The candidate NERVA nozzle assembly is a steel jacketed "U" tube nozzle with a flanged hole in the convergent section to accept the hot bleed port assembly. The nozzle meets the requirements of AGC B/P 706983-29, Nuclear Rocket Engine Nozzle Assembly Drawing; AGC 90054, NERVA Nozzle Equipment Specification, dated 15 January 1965; and AGC-90016, XE-1 Nuclear Rocket Engine Design Specification.

III. TEST OBJECTIVES

The nozzle is to be tested to accomplish the following objectives:

1. Assure structural integrity of the nozzle jacket and tubes when subjected to internal chamber and coolant pressures exceeding those during XE-1 testing.
2. Assure that the nozzle will not leak at any brazed, welded or threaded fitting or joint, or in any other manner, when subjected to internal gaseous or liquid pressures exceeding those expected during XE-1 testing.
3. Verify that all tubes, bolt coolant lines and flange coolant holes are unrestricted, and flow within design limits.
4. Perform tube volume measurements to establish that the cross sectional area of the coolant passages are within design limits.

IV. TEST DESCRIPTION

A. FLOW COEFFICIENT DETERMINATION

The nozzle is set up and flowed with water in the forward direction, i.e., from the coolant inlet to the core support flange. Water flow rate, inlet pressure, and outlet pressure are measured and recorded at three different flow rates. Approximately 180 lb/sec, 200 lb/sec, and 220 lb/sec. With this information, the K_w value is calculated using the formula:

$$K_w = \frac{\dot{W}}{\sqrt{\Delta P \cdot \text{S.G.}}}$$

where:

$\dot{W}$ = flow rate (lb/sec)

S.G. = specific gravity

K_w = flow coefficient

ΔP = difference between inlet and outlet pressure (psi)

The water flow rate is calculated by measuring the pressure difference across a calibrated orifice. The K_w value is obtained for engineering evaluation, and the data will be compared with previous nozzles to predict nozzle coolant circuit pressure drop during the XE-1 test.

B. INDIVIDUAL COOLANT CHANNEL FLOW

The pressure vessel simulator tooling is removed from the core support end of the nozzle after K_w value determination, and tubes connected to each of the core support flange exit holes. The test set up may be seen in Figure 1. The individual coolant channel flow test allows each coolant channel flow to be measured individually, using a time/weight method. It is desired that all tubes flow equally within 10% of the average flow rate; however, analyses and testing have shown that variations of 15% are acceptable.

C. RADIOGRAPHIC INSPECTION

The nozzle is given a complete radiographic inspection per B/P 706988-29, G/N 18. All coolant channels and flow cavities are inspected to detect foreign material which may be lodged in the passages.

D. GN_2 PROOF AND LEAK

Following tube brazing and any leak repair, the nozzle is pressurized to 200 psig with GN_2 and held for two minutes. The pressure is then reduced to 100 psig and leak check solution per MIL-L-25567 applied to all brazed and welded joints verifying that all joints are leak-tight when subjected to this gaseous nitrogen pressure.

E. HIGH PRESSURE PROOF AND LEAK

On completion of the GN_2 test, the internal cavities of the nozzle are pressurized for ten cycles to 1150 psig with water and held for two minutes each cycle, per 706983-29, G/N 22A, which exceeds the requirements of AGC-90054. The pressure is then reduced to 860 psig and held for ten minutes. The nozzle is checked visually to assure that no water leakage exists at this pressure.

The high pressure proof and leak test verifies the structural adequacy of the coolant channels and torus to perform satisfactorily at the design operation pressures.

F. CROSS-SECTIONAL AREA CHECK

The nozzle is drained after the high pressure proof and leak and purged with shop air or GN_2 to remove residual water. The nozzle is placed on its aft surface and the forward surface leveled within $\pm .010$ inches. The nozzle tubes are then filled to the top with a solution containing 1 part Nacconol - NRSF and 2000 parts water. The detergent serves as a wetting agent. All entrapped air is bled from the hardware prior to conducting the volume check.

The water solution is drained from the nozzle in incremental quantities to a specified water level height. The volume of water removed is carefully measured and the distance from the top of core support flange recorded. By knowing these values, the average cross sectional area between any two points may be calculated.

This measurement of the cross sectional area determines the total tube area at each station along the length of the nozzle. The data is used for engineering evaluation to compare with design values and previous nozzles.

G. CHAMBER H₂O PROOF AND LEAK

On completion of the volume check, the hot bleed port (P/N 706967-59) and hot bleed port seal are assembled to the nozzle per B/P 1114263-89. This nozzle-bleed port is assembled to the thrust chamber assembly hardware for chamber proof and leak. (See Figure 2 for Test Set Up.) The chamber and coolant tubes are simultaneously pressurized to 800 psig with water and held for two minutes per 1114263-89, G/N 7A. The test is repeated for a total of ten cycles, which exceeds the requirements of AGC-90054. The pressure is reduced to 600 psig, and the external surfaces visually inspected for leaks. The nozzle is acceptable if there is no visual accumulation of water on any surface.

The chamber proof and leak tests assures that the nozzle jacket, and the bleed port attachment is structurally adequate at a pressure above the maximum expected pressure.

H. CHAMBER HELIUM LEAK CHECK

Without disassembling, the nozzle-bleed port-thrust chamber assembly is dehydrated per 1114263-89, G/N 7B. The chamber and coolant tubes are simultaneously pressurized to 200 psig with gaseous helium. The pressure is reduced to 100 psig and the nozzle-bleed port interface is checked for leakage with leak check solution per MIL-L-25567. Any visible evidence of bubble formation shall be cause for rejection.

The chamber helium leak check assures the nozzle-port seal will perform its intended function.

I. COOLANT CIRCUIT HELIUM LEAK CHECK

The nozzle is cleaned and dehydrated, and the bolt coolant lines, which have been tested, cleaned and calibrated on separate operations, are installed. All threaded plugs and seals are installed, torqued, and lockwired. The internal cavities of the nozzle are pressurized to 200 psig with helium and held for two minutes and then reduced to 100 psig (this leak test pressure exceeds the leak check pressure of 50 psig specified in AGC-90054). All fittings, braze and welded joints are checked with leak check solution per MIL-L-25567. Any visible evidence of bubble formation shall be cause for rejection.

V. CLEANING

The nozzle coolant channels are flushed and backflushed with water at 200 lb/sec until clean as evidenced by an absence of particles in a catch screen of approximately 1000 micron mesh. The nozzle is subsequently cleaned to AGC-STD-9001 to meet the cleanliness levels specified in AGC-STD-9007. Cleanliness of the nozzle is monitored by the Engineering and Product Assurance Division.

VI. FINAL ACCEPTANCE

The final acceptance of this nozzle for use on XE-1 is accomplished through Material Review Board action.

INDIVIDUAL COOLANT CHANNEL
FLOW FIXTURE

FIGURE 1

CHAMBER PROOF AND LEAK FIXTURE
FIGURE 2